FUZZY LOGIC MODEL FOR PREFERENCE OF PARAMETERS IN NETWORK QoE ANALYSIS

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Fuzzy Logic Model for Preference of Parameters in Network QoE Analysis

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DECLARATION

This thesis is my original work and has not been presented for a degree or award of any type in any other university

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DEDICATION

I would like to consecrate this research work firstly to the Most High God for the knowledge and wisdom that directed my research work towards this line of focus. Secondly, to my networks and entire family members for unending assistance and inspiration rendered to me inclusively.

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Finally, I seek to thank my Support system and Family for their backing and inspiration all through my period of study. May God exalt you all and guide you with these wise Quotes; “Start where you stand, use what you have and sort out whatever you can” by Arthur Ashe. “Moreover, there are no traffic congestions on the additional mile” by Zig Ziglar.

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ABBREVIATIONS AND ACRONYMS

AS	Autonomous systems
Bit/s or bps	Bits per second
COGS	Center of gravity method for singleton
FIS	Fuzzy inference system
FLC	Fuzzy logic controller
FLS	Fuzzy logic system
GB	Gigabyte
H	High
ISPs	Internet service providers
ITU	International Telecommunication Union
L	Large
M	Medium
MOS	Mean opinion score
P/s or pps	Data packets per second
PD	Priority degree
PSNR	Peak signal to noise ratio
QoE	Quality of experience

QoS	Quality of service
RAM	Random access memory
SLA	Service level agreement
SLAs	Service level agreement(s)
STCS	Smart traffic control systems
TQ	Traffic quantity
VH	Very high
VL	Very low
WSN	Wireless sensor network
WT	Waiting time

ABSTRACT

Two important Quality of experience (QoE) parameters in computer networks service related performance metrics are throughput and delay. A low delay indicates high network efficiency thus high throughput. Similarly, the entire four parameters linked to the integrity of service are considered to be primary factors affecting any computer network. The study's objective is to identify the vital primary parameters with preeminent results to be kept into consideration when analyzing network QoE by using fuzzy logic methodology. A local area network of 64 nodes was used for data collection of the four parameters namely: Throughput, delay, packet loss and jitter. Fuzzy logic methodology was implemented using experimental research design. Five input linguistic terms were utilized: High, very high, medium, very low and low. Five output linguistic terms were used to refer to the opinion scores: Bad, poor, fair, good and excellent. The four parameters were used for the four variables model generating 625 rules (5^4). The rules were further condensed to 240 logical rules centering on expert knowledge. Likewise delay and throughput were used for the two variables model spawning 25 rules. The rules were further condensed to 17 logical rules centering on expert knowledge. Firstly, the two models analysis results were compared in the rule viewer where the four parameters model had better QoE values for different setups compared to the two parameters model. Secondly, the analysis of results using independent sample T-test technique which compared mean performance of the two models was done. The results specified a significant consequence using the entire four parameters model compared to using a two parameters model for analysis of computer network QoE whereby the score for the p-value based on a confidence interval of 0.95 was 0.017, indicating a significance difference of the 2 models. The target population for this model is the service providers enabling them to have the best receptive measures to deal with network service provision in order to deliver the quality of service (QoS) as per service level agreement (SLAs) thus achieving finest network QoE.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Quality of service (QoS) is a key element that influences Quality of experience (QoE) as illustrated in the correlation between QoS and QoE in figure 2.1. QoS is the level of compliance of a service provided to a consumer by a supplier in accord to a contract amongst them (ITU-T, 1996). QoS in computer networks is to guarantee transmission quality to certain network traffic over numerous technologies and identify errors that arise in the traffic network (Ahmed & Rosilah, 2020). This ensures ease of access of good service by end users thus greatly influencing QoE analysis.

As the service provision necessities of network applications shift from high throughput to high media excellence, interactive media, and approachability, the definition of Quality of experience (QoE) has become multifaceted.

QoE is defined by International Telecommunication Union (*ITU)* generally as the competence of an application or service as alleged subjectively by users (ITU-T, 1996). QoE in the perspective of communications networks is determined as the user's degree of amusement or displeasure of an application or service (Brunnstrom, et al., 2013)

Numerous models have stood developed for network QoE analysis in terms of both traditional quantitative methods and qualitative methods. Mean opinion score (MOS) is the frequently utilized traditional quantitative method to provide user satisfaction level. The MOS is articulated as a single rational digit, usually in the range of 1–5, where 1 is the bottommost perceived value and 5 is the uppermost perceived excellence. Other MOS range of values is similarly promising, dependent on the evaluation scale that has been utilized in the essential assessment. This model is thus quantitative in nature despite the fact that user opinion is subjective and not definite thus cannot be noticeably dignified using quantitative techniques (ITU-T, 1996).

Currently, there are quite a lot of smart technologies in use for analysis of user satisfaction in QoE including Sebastian et al., (2013) who proposed an approach for judging network achievement in provision of mobile internet amenities centered on QoE (users' opinion). This method based on the relationship concerning QoS elements and the QoE. Two neural network models were utilized to acquire the ultimate correlation between the models. Exhausting a 3G android phone and a 3G modem networks, the final model was ascertained to accumulate five contrasting cells statistics. Network element results were consumed for validating the model.

Furthermore, Emad et al (2016) proposed a multilayered forecasting model grounded on random neural networks method aimed at assessing perceptual excellence of mobile audiovisual key factors stirring video worth without referencing. Analysis results indicated a substantial predictableness whereby R-squared correlation and root mean squared error of 0.90 and 0.39 respectively.

Likewise, Anastasia and Budi (2016) evaluated consumer contentment of two companies i.e. Grab and GO-JEK twitter's data by means of sentiment analysis since both of them use twitter for influencing customers and service promotion. Grab and GOJEK keywords were captured from 126,405 tweets for analysis and classification utilizing three algorithms: Naive Bayes, decision tree and support vector machine. Finally, score based on net sentiment calculation was associated with consumer contentment by classification grades. The analysis results revealed Grab's client contentment being greater than Go-JEK's. Moreover, consumers mainly quantified both twitter accounts for ruthless involvement rather than positive remarks.

Moreover, Fuzzy set theory is widely consumed for qualitative valuation of user satisfaction. This is a research method dealing with complications concerning unclear, subjective and imprecise decisions thus capable to compute the linguistic aspect of presented data and preferences for decision making (Mehrdad & Abbas, 2011)

Fuzzy logic exploits ambiguity and lack of information to make decisions from ambiguous and imprecise facts (Hamdy, Hesham, & Imane, 2020)

Recently, the diversity of usage of fuzzy logic has improved considerably. The uses range from end user merchandises such as microwave ovens, washing machines, camcorders and cameras to engineering process control, manufacturing of medical equipment, decision-support systems (DSS) and network analysis.

In reference to network analysis scenario, all network assessment models can be grouped into two main sets: quantitative and qualitative. Qualitative techniques do not own quantitative standards and cannot certainly be assessed by numerical numbers. At such instances, linguistic terms are used up to assess results of qualitative measurability (Ezutah & Kuan, 2010). Fuzzy logic control is worthwhile when the problem is challenging to be resolved with quantitative methods (Shirouyehzad et al., 2011).

Users express their sentiments about a product/service in usage of linguistic terms nonetheless the term satisfaction would have diverse grades to each user thus there is need to have an implicit measure of users' level of satisfaction (QoE). QoE valuation is complicated as it attempts to quantify a subjective metric although the user understanding relies on a number of aspects that cannot smoothly be assessed.

This research was rationalized to be conducted in view of the fact that human perception is subjective and not precise. This means human perception cannot be precisely measured using quantitative methods. Some of computer networks analysis models are quantitative in nature, thus there is need to use qualitative techniques like fuzzy logic technique to handle this challenge. Fuzzy logic is preferred aimed at several motives:

- QoE variables and linguistic terms are ambiguous in nature.
- Fuzzy inference system (FIS) works with linguistic variables and linguistic terms which are appropriate when inferences have to be extracted subjectively.

- Fuzzy logic is a more general concept, and it may include Bayesian approach as a subset.

In addition, fuzzy logic has comfort of implementation i.e. whenever contemporary input data or new rules are introduced into the system, no need to re-train the model thus usable in outstanding actions when the scope changes as echoed by (Constantin, 2020).

Besides, fuzzy logic exploits ambiguity and lack of information to make decisions in reactive routing protocols which affect networks as deliberated by (Hamdy, Hesham, & Imane, 2020).

Moreover, fuzzy logic offers a very creative clarification to complex problems in all fields of life as it resembles human thinking thus best for QoE study as highlighted in (geeksforgeeks, 2021).

Based on the background study, fuzzy logic technique tends to outperform the other methods based on various ground and supporting literatures as discussed thereby being the preferred methodology to carry out this research.

Among discussed models, none merged all-inclusive parameters of network integrity of service. These parameters represent the primary factors aimed at QoS evaluation of any network in an ideal situation thus fundamental in network QoE performance analysis.

Based on the discussed challenges, this research collected LAN dataset, developed two models based on integrity of service parameters utilizing fuzzy logic, established the need of a four parameters model in comparison to the two parameters model. The analysis results indicated the four parameters model outperformed the two parameters model. The interest behind was to facilitate preference of parameters under consideration in network QoE analysis.

1.2 Problem statement

In a typical situation, two important QoE parameters in computer networks are throughput and delay. A low latency/delay indicates high network efficiency thus high throughput (Mnisi.N.V, 2016)

In (Woods & Mohammed, 2013), an affine fuzzy logic based model that can estimate the visual perceptual quality for different video content types using a combination of network level and application level QoS parameters was presented. Video QoE was anticipated in terms of the mean opinion score (MOS). The outcomes indicates that the QoE is video content dependent.

Integrity of service parameters: Throughput, delay, packet loss and jitter have been looked in previous work for (Farid et al.,2014) however that work concentrated on quantification in wireless and mobile networks while this study concentrated on local area network. Moreover, this study concentrated on integrity of service parameters in combination with five input linguistic terms: High, low, very high, very low and medium, Five output linguistic terms: Excellent, good, poor, bad, and fair, unlike in (Farid et al., 2014) work.

Ebrahim and Hefny (2018) discovered a fuzzy logic based approach which was in use for maintaining VoIP (voice over internet protocol) QoE. Quality in the network was affected by jitter, delay and packet loss. The output variable was new token. L-low, VL-very low, VH-very high, H-high and M-medium were the linguistic values in use.

Among existing models, none of them incorporated the entire four parameters of network integrity of service in combination with the utilized five input and output linguistic terms. These parameters represent the primary factors aimed at QoS evaluation of any network in an ideal situation (Yan et al., 2020) thus failure to integrate all of them for performance analysis will not craft the best QoE results.

Based on the discussed challenges, this research collected data using linux MTR tool, developed a four parameters model based on integrity of service parameters centered on fuzzy logic methodology, established the need of a four parameters model in comparison to the two parameters model utilizing rule viewer technique and independent T-test method. Moreover, it outlined the best QoE parameters combination to yield paramount results in network analysis. The interest behind was to facilitate preference of parameters in network QoE analysis utilizing fuzzy logic model.

1.3 Justification

The developed model utilized four variables including throughput, delay, packet loss and jitter; they are principal factors for QoS assessment of any network (Yan et al., 2020).

Five input linguistic terms were in use: Low (L), very low (VL), medium (M), very high (VH) and high (H) since it accommodates a wide range of values. Five output linguistic terms were identified: Bad, poor, fair, good and excellent experiences resulting to 625 rules (5^4 i.e. input linguistic terms rose up to the power of variables). Among the 625 rules, only the 240 logical rules were executed by the fuzzy inference system to produce viable output results.

The developed model consisting of four variables was compared to the two variables model; throughput and delay for extensive simulation to examine the effectiveness of the models. These two parameters are important QoE parameters in computer networks (Mnisi.N.V, 2008). Likewise delay and throughput were used for the two variables model spawning 25 rules. The rules were further condensed to 17 logical rules centering on expert knowledge. Firstly, the two models analysis results were compared in the rule viewer where the four parameters model had better QoE values for different setups compared to the two parameters model. Secondly, the analysis of results using independent sample T-test technique which compared mean performance of the two models was done. The results specified a significant consequence using the entire four parameters model compared to using a two parameters model for analysis of computer network QoE whereby the score for the p-value based on a confidence interval of 0.95 was 0.017, indicating a significance difference of the 2 models.

The potential beneficiaries of this research work are Internet service providers (ISPs) in that it will aid the enactment of a mechanism that will empower ISPs to deliver best reactive course of action to users' QoE ratings thus achieving the QOS as per service level agreement(s).

1.4 Objectives

1.4.1 General objective

To develop a fuzzy logic model for preference of parameters in network QoE analysis.

1.4.2 Specific objectives

i) To analyze the existing models used in QoE analysis.
ii) To design fuzzy logic based QoE modeling architecture.
iii) To develop the proposed fuzzy logic model for analysis of computer network QoE.
iv) To evaluate the performance of developed model and compare it with traditional two variable model.

1.5 Research questions

i) What are the challenges with the existing QoE models?
ii) Which tools and techniques are vital to aid the design of fuzzy logic based QoE modeling architecture?
iii) What are some of the improvements that can be made on existing computer networks analysis models to make them better?
iv) Which evaluation and comparison techniques are used to evaluate and compare performance of the developed model with existing model(s)?

1.6 Scope

i) A research was conducted on the areas of computer networks quality of experience.

ii) A research was conducted on integrity of service parameters; delay, jitter, packet loss and throughput.

iii) Data was collected on integrity of service parameters and analyzed using independent sample T-test technique and in MATLAB rule viewer.

iv) A design of the model was generated for use in testing phase.

v) The operation environment for QoS performance analysis was intended for non-multimedia network in developing countries environment as a case study.

1.7 Limitations

- This work utilized fuzzy logic methodology rather than other techniques like support vector machine, neural network, decision tree, naive bayes etc. The limitation was that the model was to be developed with other methods or techniques and the results compared with the developed fuzzy logic model in order to test the effectiveness of other methods/techniques.

- This work selected Mamdani fuzzy inference system (FIS) and not Sugeno FIS. This was a limitation since it is advisable to use both FIS to develop the model in order to have clear comparison of the two FIS results and choose the best for use.

- In this work, accessibility and/or retainability QoE parameters were not handled. The respective underlying QoS-related parameters were to be incorporated into the model to test the effectiveness of the model which was not part of the scope.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter divulged into various approaches for analysis of qualitative performance including traditional approaches to analysis of network QoE, fuzzy logic models for analysis of qualitative performance, conceptual framework, other smart technologies in use for analysis of quality of experience, critiques of the prevailing literature applicable to the field of study and gap in the research. An understanding of this helped form the basis of the research methodology for use in this research work

2.1.1 Network quality of experience (QoE)

Quality of experience (QoE) is determined as broad acceptance of a service or an application as considered subjectively by users (ITU-T, 1996)

The impression of QoE is applied to assess user contentment level as presented in Figure 2.1.

Therefore, centered on aforementioned description of QoE, network QoE can be outlined as general acceptance of the network service(s) as considered subjectively by users.

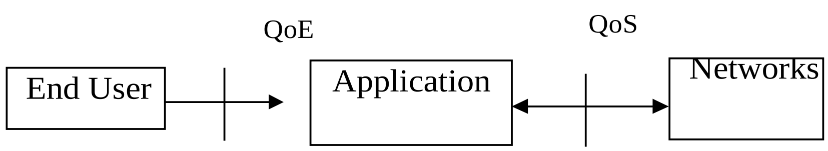


Figure 2.1: Correlation between QoE and QoS

2.1.2 Fuzzy logic

Fuzzy logic has been termed as computation using words (Zadeh L. , 1996). Fuzzy logic is a renowned method that handles complications with vague and partial data.

Fuzzy methodology deals with consumers' fuzziness by generating partiality relationships using inference rules and fuzzy sets (Negnevitsky, 2002).

Fuzzy logic emanates when conventional reasoning dissatisfies. It is a computing standard based on human intellectual. Crucial conception in fuzzy logic is through use of linguistic variables i.e. variables whose measures are words in human language (Kharola, Kunwa, & Choudhury, 2015)

Fuzzy logic is a reasonable, stable logic patterned by imprecise perceptive of humans. As one of the concepts of mathematical methods, fuzzy logic responds to regularly varying variables. It defies traditional logic by not being limited to predictable binary values of 1 and 0 (Zadeh L. , 1965)

The factual domain linguistic used in fuzzy mechanism empowers engineers to integrate vague, imprecise human thinking into computers via linguistic forming, contrasting to precise modeling. This significantly streamlines the design and adaptation of fuzzy logic system.

Shruti and Mudholkar (2013) developed Fuzzy set theory to address circumstances where judgement needs to correctly evaluate and process data that is vague in nature.

Fuzzy sets offer conceptual framework in addition to analytical means to answer real world complications where there is no specific facts and accuracy as highlighted in (Sirigiri et al.,2012)**.**

Human interpretation is impacted in the logic of fuzziness and judgment. The aim of fuzzy logic ought to style computers reason similar to humans. Fuzzy logic concerns vagueness basic to human intellectual, natural language noting its nature being dissimilar as of randomness as envisioned in (Zadeh, 1983).

Fuzzy logic concept possibly supports mechanisms to comprehend and react to ambiguous human perceptions such as hot or cold, large or small etc. Similarly it may possibly offer a reasonably modest approach to influence positive inferences from vague data as featured in (Zadeh L. , 1965).

2.1.3 Integrity of service

Integrity of service encompasses upholding uniformity, accuracy and reliability of data over its whole life cycle. Information need not be altered during transit, and phases must be in use to guarantee information not being changed by unapproved individuals for instance, in privacy breach as defined by (Rouse et al., 2014).

Network integrity of service elements are principal factor aimed at quality-of-service exploration of any network. They include delay, jitter, throughput and packet loss parameters as discussed in (Farid, Shahrestani, & Ruan, 2014)

2.1.4 ISPs (internet service providers)

Internet service provider is an enterprise that offers consumers internet access. Data may be conveyed by means of a number of technologies comprising cable modem, dial up, wireless, DSL or dedicated high-speed interconnects in reference to (ITU-T, 1996).

Amongst the leading nationwide as well as regional ISPs include IBM global network, AT&T world net, Netcom, MCI, PSINet and UUNet. Examples of internet service providers (ISPs) in Kenya include Zuku, Safaricom, Airtel, Orange, Faiba internet, Dimension data formerly known as Internet solutions etc.

2.1.5 Quality of service (QoS)

Quality of service (QoS) in computer networks is to guarantee transmission quality to certain network traffic over numerous technologies and identify errors that arise in the traffic network as defined by (Ahmed & Rosilah, 2020).

In order to evaluate QoS of computer networks competently, network and service correlated metrics must be acknowledged wisely. The existing literature in this perspective evaluates varied features of corresponding metrics. Each amenity has crucial parameters that critically impact its achievement as highlighted in (Farnaz et al.,2014).

A number of research works advocate for QoS valuation of any network, it is worthwhile to pick corresponding QoS metrics correlated to QoE parameters.

QoS parameters are elements that affect the value of a resource offered. They are vital in service level agreement (SLA) scrutiny as identified by (Markus et al., 2010).

A unified network QoS assessment value can streamline the manner of network QoE valuation. Mappings between QoE and QoS parameters are illustrated in Table 2.1 below:

Table 2.1: Mapping between QoS and QoE interrelated parameters (Farnaz et al., 2014)

QoE parameters	Underlying QoS-related parameters
Accessibility	• Unavailability • Security • Activation • Access • Coverage • Blocking • Setup time
Retainability	Connection loss
Integrity of Service	• Throughput • Delay • Delay variation/Jitter • Packet loss

In this work, the underlying QoS parameters interrelated to integrity of service QoE parameters are under consideration as the area of study. These are prime factors aimed at QoS assessment of any computer network as reiterated by (Yan et al., 2020).

The significance magnitudes of these parameters are typically stable. Nonetheless, the ranks can differ centered on consumer perspectives and service level agreements even though, this might not openly distress the performance of these parameters in influencing QoS levels, though it might upset the QoE alleged by users.

2.2 Traditional approaches for analysis of network QoE

Mean opinion score (MOS) is an arithmetic assessment in a scale of 1-5 which is used as an index for expressing the QoE whereby 1 signifies the lowermost purported quality while 5 is the utmost alleged worth. The standard scores aimed at MOS are available in ITU-T commendation emphasized in (ITU-T, 1996).

The valuation scales provided in Table 2.2 below are MOS for assessing QoE value of services and applications. For instance, these MOS values were utilized to assess users' experience of web browsing as deliberated by (Junaid et al., 2010).

Table 2.2: Opinion scores recommended by ITU-T

Score	Sequence quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

Fuzzy logic models for objective assessment

Objective assessment of QoS has been minimally applied for QoE assessment.

Ataeian and Darbandi (2011) proposed analysis of quality of experience on a study of response time. For recognition of a fuzzy association, an innovative term titled Fuzzied opinion score (FOS) expressing a fuzzy quality scale was presented. Fuzzy data mining technique was utilized to generate vital quantity of fuzzy sets.

Objective assessment approach still comes with its share of challenges since QoE parameters are vague and subjective as delineated by (Hamam, Eid, Abdulmotaleb, & Georganas, 2008). In such a scenario, a mechanism like fuzzy logic technique is necessary to plot ambiguous responses to crisp values subjectively.

Currently, subjective valuation of QoE has enticed growing responsiveness equated to objective valuation of QoS. This observation prompted scholars to further investigate on the causal relationship between smart technology and QoE measurement. Fuzzy logic technique is one of the smart technologies in use. Others include: Support vector machine, neural network, decision tree, naive bayes etc.

Fuzzy logic tends to have a higher precedence when analyzing QoE as fuzzy logic is a distinguished method handling complications having vague and partial data as discoursed by (Negnevitsky, 2002). Moreover, fuzzy method deals with users' fuzziness by generating preference affairs achieved by fuzzy sets and inference rules.

Several researches have been done on fuzzy logic in relation to QoE though little has been done on fuzzy logic method for analysis of computer networks QoE.

2.3 Fuzzy logic models for analysis of qualitative performance

Several researches have been done on fuzzy logic in relation to quality performance. Hamam, Eid, Saddik, & Georganas (2008) conducted a research study on a Fuzzy Logic method aimed at assessing QoE of haptic-based usage utilizing Mamdani FIS. Psychological, rendering quality and physiological variables were under consideration.

Ataeian and Darbandi (2011) proposed a network response time QoE analysis based on fuzzy logic. This provided a fuzzy association between QoS and QoE factors utilizing "Fuzzied opinion score" (FOS) and fuzzy data mining to design the fuzzy sets.

Onifade (2013) proposed a productive algorithm for conveying network packets for enhancing QoS in mobile network utilizing fuzzy logic. Latency, bandwidth and range network parameters were in use. Input linguistic terms comprised of high, normal and low. The output variables encompassed excellent, good and poor. The outcomes specified fuzzy logic technique for assurance of QoS pertaining to network packets.

Hawi, Okeyo, and Kimwele (2015) proposed a fuzzy logic combination of wireless sensor network (WSN) aimed at traffic light regulation in a four type roundabout. Smart traffic control systems (STCS) utilized real time statistics for green light distribution based on waiting time (WT) and traffic quantity (TQ) thus regulating a priority degree (PD) value that controls green light signaling based on maximum PD.

Pokhrel (2015) exhibited QoE approximation aimed at choosing web services by means of fuzzy rough hybrid technique whereby rough set theory outlined the rules for fuzzy system. QoS parameters in use comprised of reliability, availability (sec) and execution time (sec). Input linguistic terms were high, medium and low while output linguistic terms were bad, poor, fair, good and excellent.

Jeevan (2015) analyzed effects of network QoS elements on video QoE aimed at VoD (Video-on-demand) amenities. Jitter, burst packet loss and packet loss rate parameters were utilized. Perceptible but not annoying, slightly annoying, annoying, very annoying and imperceptible were input linguistic terms. Slightly annoying, very annoying, perceptible but not annoying, annoying and imperceptible were output linguistic terms. Grading of the video footage was based on alleged signal weakening.

Ebrahim and Hefny (2018) discovered a fuzzy logic based approach which was in use for maintaining VoIP (voice over internet protocol) quality in a network affected by jitter, delay and packet loss parameters. New token, bandwidth rate and buffer size variables permitted to improve the output variable i.e. new token through fuzzy logic model for VoIP quality. The linguistic values for new token were {L-low, VL-very low, AV-average, BA-below average, H-high, VH-very high and AA-above average.}

2.4 Conceptual framework

The mappings between network integrity of service QoE and corresponding QoS parameters in Table 2.1 resulted in to conceptual framework model in MATLAB

Environment as demonstrated in Figure 2.3

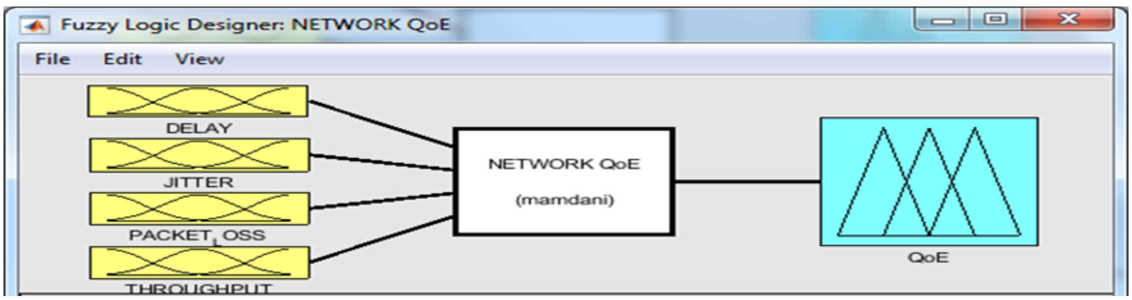


Figure 2.4: Conceptual framework model for mappings between network integrity of service QoE and corresponding QoS parameters

The model presents the four independent variables under network integrity of service QoE: Throughput, jitter, delay, and packet loss. Dependent variable is the network QoE value. The network QoE output value depends on the four independent variables performance. These four independent variables are discussed below:

Delay: This is where the information consumes some time to reach the destination point (Gouveia & Magedanz, 2015). This parameter is intrinsic to communications. Is a vital factor used in evaluating services offered in real-time like videoconferencing and (VoIP) voice over internet protocol (Zi et al., 2013). Delay is also known as latency.

Packet loss: Is packet of datum failing to arrive to respective endpoint(s) when conveyed through computer networks (Mnisi, Oyedapo, & Kurien, 2008). Packet-based parameters are reasonably favorable for evaluating service excellence (Winkler & Mohandas, 2008). Packet loss greatly influences assessment of PSNR (peak signal to noise ratio) as a fundamental factor for assessment of video QoE (Alreshoodi & Woods, 2013).

Jitter is described as fluctuations in delay occurrence (Gouveia & Magedanz, 2015). It occurs due to inconstant transmission of delaying network packets as a result of routers' internal routing changes, flow congestion etc. It’s a vital factor for assessment of multimedia network (Winkler & Mohandas, 2008).

Throughput is the quantity of data in a particular time conveyed over a network link (Mnisi, Oyedapo, & Kurien, 2008). Throughput is essentially synonymous to bandwidth consumption (Guowang et al., 2016).

The four parameters are deeply related to each other as persistent existence of jitter in a network leads to delay, when delay persist it leads to packet loss and when packet loss persist in a network, it directly affects the general network throughput.

2.5 The critiques of the existing literature relevant to the study

Limited models exist that analyze qualitative analysis of QoE though most of them have limited network parameters. For instance, research work in (Pokhrel, 2015) exhibited a fuzzy-rough hybrid technique for QoE valuation aimed at selection of web services. Reliability, execution time and availability QoS parameters were utilized for analysis.

Jeevan (2015) revealed the analysis of the effect of diverse network quality of service elements on video quality of experience for video-on-demand amenities. Network parameters in use included: Jitter, packet loss rate and burst packet loss.

Ebrahim and Hefny (2018) discovered a method based on fuzzy logic in use for maintaining VoIP quality in a network which was affected by several network factors including new token, buffer size and bandwidth rate.

Grounded on review of work cited, it’s a clear indication that each research work used different types of network parameters and linguistic terms. The approach used to select each one of them for usage was not clearly outlined.

Additionally, none of the models integrated the entire four aspects of integrity of service for network performance analysis i.e. Jitter, packet loss, throughput and delay in combination of same linguistic terms and linguistic variables as outlined in this research work. Most of the researches have either utilized some of these parameters or some of these parameters in combination with other metrics or these parameters with different linguistic terms and linguistic variables. These four elements are considered to be the primary factors which affect any computer networks (Farid, Shahrestani, & Ruan, 2014). Consequently, this study was inspired to address this gap by presenting an advanced approach for networks QoE assessment by use of fuzzy logic putting into consideration the best combination integrity of service network elements for network analysis.

2.6 Research gap

In network QoE assessment, it is worthwhile choosing QoS elements correlated to relevant quality of experience factors. The network QoE parameters include accessibility, retainability and integrity of service each of them having corresponding QoS parameters as discussed in previous chapters (Farid, Shahrestani, & Ruan, 2014).

Limited research work deliberated in the literature review reflected on the underlying quality of service elements associated to the integrity of service quality of experience metrics. None of them reflected the all-inclusive four parameters: Throughput, delay, packet loss and jitter in combination of same linguistic terms and linguistic variables as outlined in this research work. Most of them have partially included some of these parameters or utilized some of these parameters in combination with other metrics. The four are considered to be the primary parameters for QoS quantification of any network.

Throughput, delay, packet loss and jitter have been looked in previous work for Farid et al., 2014 however that work concentrated on quantification in wireless and mobile networks while this study concentrated on local area network. Moreover, this study concentrated on integrity of service parameters: Delay, jitter, packet loss and throughput in combination with five input linguistic terms: High, low, very high, very low and medium, five output linguistic terms: Excellent, good, poor, bad and fair, four variables: Jitter, packet loss, delay and throughput unlike in Farid et al., 2014 work.

2.7 Summary

In evaluating quality of service of any network competently, service and associated network elements should be acknowledged judiciously.

In summary, there is a necessity to include the entire four elements associated with integrity of service metrics since they are considered to be primary factors affecting any computer networks (Farid et al., 2014).This was evidenced by comparing the output results obtained from two parameter model: delay and throughput which are considered as important QoE parameters in computer networks service related performance metrics (Mnisi.N.V, 2008) in comparison with the four parameter model which are considered to be the principal factor for QoS exploration of any network (Farid, Shahrestani, & Ruan, 2014). The analysis results specified the model with four parameters were vital primary parameters with preeminent results to be kept into consideration when analyzing Network QoE.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This section manifested the research design, population under study, justification of sampling frame of choice, sample & sampling technique, research instruments used in data processing and analysis, data collection procedure involved in the study, design methodology, data processing and exploration.

3.2 Research design

This research work focused on determination of network parameters for use in network QoE analysis using fuzzy logic, a study on integrity of service. The research approach in use was experimental research design. This necessitated comprehensive restriction over minor variables bringing the effect that witnessed effects on dependent variable is as a result of transformations in independent variable.

In this experiment, data was acquired from autonomous systems (AS)/ network connections using linux MTR tool. This data was acquired inform of TXT file (.txt) and exported to Ms. Excel for processing in order to execute data cleaning. The processed data was presented in form of excel workbook format (.xlsx) each having crisp data for throughput, delay, packet loss, jitter and user’s dataset. Obtained crisp data for throughput, delay, packet loss and jitter were used as input dataset for developed model.

The crisp values organized in tables were presented to MATLAB environment as input data for analysis basing on fuzzy rules and membership function. Fuzzification was implemented by means of triangular membership function due to computational efficiency. The acquired results were further defuzzified using weighted average method in order to acquire an output crisp value. The obtained value represented network QoE analysis result used for decision making.

3.3 Population

For experiment purposes, the target population was network nodes/autonomous systems connected to a network. These nodes were used for provision of the relevant network dataset (delay, jitter, packet loss and throughput) for analysis purposes.

3.4 Sampling frame

Consecutive sampling technique was used to determine the sampling frame. This technique explores all available objects in the population that is to be studied.

The subjects were network nodes therefore resulting to using all the available network nodes in the network. This technique is deliberated among the dominant non-probability sampling techniques as it includes totally all available items of study in the population making the fragment a superior depiction of the whole population (Explorable, 2019).

There was a total of 64 network nodes in the network setup. The sampling frame implicated 64 samples/ autonomous network connections/systems for the purpose of data collection from the designed network setup.

3.5 Sample and sampling technique

The nature, type and purpose of the study determine the sampling technique to be used. Non-probability sampling method was used to conduct the research. In this technique, subjective approaches are utilized to select the components to be incorporated in the sample (Ilker, Sulaiman, & Rukayya, 2016).

This method was worthwhile as both time, budget and personnel were insufficient thus using this nonprobability sampling technique as its economical compared to probability method and frequently effected more speedily (Ilker, Sulaiman, & Rukayya, 2016).

Non probability sampling technique consists of various types including: convenience sampling, consecutive sampling, quota, judgmental sampling, snowball sampling etc. The nature and type of study determines the choice to be implemented.

In this work, consecutive sampling was in use. A total of 64 network connections/ autonomous devices were identified as the sample size. This sample size was selected as it is easily available for data collection. Moreover, it included all subjects (network devices) that were available in the network setup that made the sample a superior depiction of the total population thus having an element of consecutive sampling method.

3.6 Research instruments

The instruments were divided into two; hardware and software instruments:

Software requirements:

Linux MTR tool: This allowed for live network data extraction.

Data cleaning and presentation tool: Ms. Excel performed the cleansing task and presented useful data inform of Ms. Excel worksheet (.xlsx) format

MATLAB software: Implemented plotting of data/functions, construction of graphical interfaces and implementation of the methodology etc.

Libraries for standard membership function: Triangular membership function.

Interpreters for fuzzy inferences: Executed mamdani fuzzy inference system utilized in analysis where rules and membership functions were changed rapidly for output results.

Documentation tools: Ms. Visio 2010, Ms. Word 2010, visual paradigm 15.2 was used to accomplish the documentation of this research work.

Hardware requirements:

Processor genre: Intel® Core™ i5-6200U CPU @ 2.40 GHz

Installed memory size: 4 GB RAM.

Hard drive capacity: 250 GB.

3.7 Data collection procedures

The techniques used to collect data (fact finding approach) in this work embraced studying existing literature, observations and experiment.

i) Studying existing literature

This research was mostly built upon the course work done and elements of past research. This formed a rich source of information and was the basis of all the other data collection techniques used. It allowed for an exhaustive review of the existing related work done; the accumulated theories, knowledge, methods, and techniques. The bodies of knowledge used as references included: studying journals, online articles, conference proceeding papers, reports and technical manuals.

This tool was effective in helping to identify existing gaps.

ii) Observations

This tool was inevitably employed in analysis of network QoE activities. Surveillance on network users' reaction on changes in network variables and inspection of the network users' feedback enabled firsthand collection of data.

iii) Experiment

The experiment involved use of tools and techniques to execute data collection and analysis tasks. Throughput, delay, packet loss and jitter parameters live data were collected through the designed network setup. Linux MTR tool was used for data collection. The collected data in the experiment acted as raw data for use in developed model designed by means of Mamdani FIS. The developed four variables model was analyzed and compared with the two variables model using independent sample T-test method.

3.7.1 Study on integrity of service parameters and ascertaining the collected data

This objective was achieved by extracting data from the designed network setup by use of linux MTR tool.

Data collection procedure: data extraction

There was a vast challenge when it comes to data extraction of network QoE data. These factors ranged from the type of tool to use, the kind of data to acquire, the method to use for data cleansing to make it relevant for use etc.

Data was extracted from 64 autonomous systems (AS) acquired inform of txt file (.txt) using linux MTR tool.

MTR (My traceroute or Matt's traceroute) is a software package having the functionality of both ping and traceroute packages in one structure.

There are two types of MTR tools: Windows MTR and ubuntu linux MTR tools. MTR tool for windows has a limitation of the network parameters data acquired as it tends to produce specific parameters without the option to customize on specific parameters' data needed for the research.

Using windows MTR (WinMTR):

Running windows MTR uses a GUI.

This is achieved by opening WinMTR, writing the endpoint address in the host textbox lastly clicking the start button to initiate data report generation.

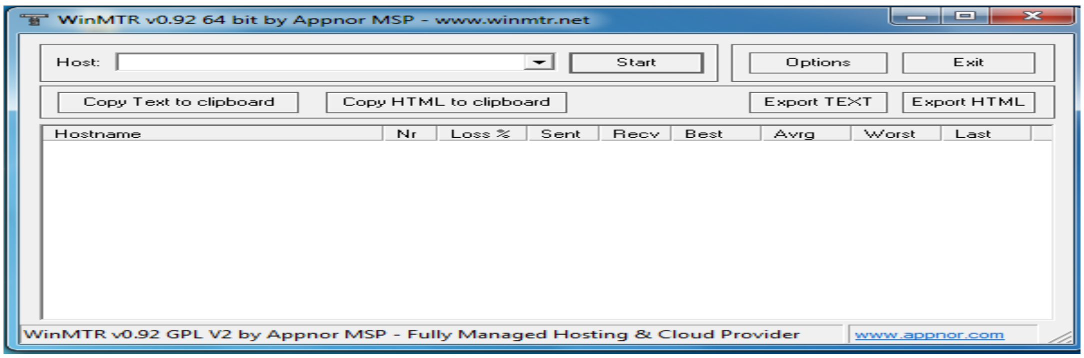


Figure 3.1: Windows MTR GUI

The reports run continuously in an interactive environment till you press stop. The interactive manner reveals updated round trip data for each internet node.

In the report, individual named line denotes a network hop. Hops are nodes that network packets use as a path to reach the endpoint.

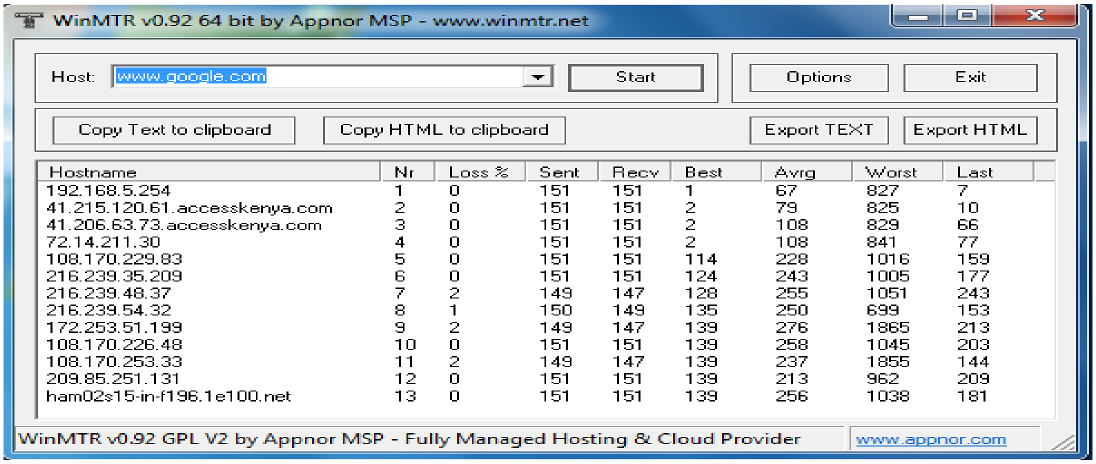


Figure 3.2: Windows MTR interactive report

MTR offers valued indicators concerning stability of the link between communicating devices in seven columns as discussed below:

The calculation of packet loss in percentage for respective hops is represented by “Loss%” column.

The total sent packets is denoted by “Snt” column whereas the total received packets is indicated under “Recv” column

“Wrst”, “Avg”, “Last”, and “Best” columns are used for quantifying latency in milliseconds (MS) whereby latency of last packet to be sent is denoted by “Last” column, “Avg” column indicates the mean latency of entire packets, “Best” column displays the best or shortest round trip duration while “Wrst” column signifies the worst or longest round trip duration of a packet to and from the host. The emphasis of consideration when measuring latency is the “Avg” column.

In some versions of windows MTR, “StDev” column determines individual latencies standard deviation for the hosts. The higher the standard deviation, the higher the inconsistent latency measurements were.

To solve such a scenario, “Best” and “wrst” columns latency quantities are averaged to ensure best depiction of authentic latency rather than fluctuated results.

Advantages of ubuntu linux MTR tool over windows MTR (Win MTR tool):

Linux MTR has the option to customize fields needed for data collection i.e. it’s possible to customize the number of network parameter fields’ data collected to meet your demand. Unlike in WinMTR, the data is provided in a standard seven column fields thus may end up capturing unnecessary dataset.

Linux MTR has the option to find help thus able to maneuver around the various commands needed; attained by the command “man 8 MTR” to get help menu.

Linux MTR has the option to export data for use in various formats including csv, txt, html, report mode, report wide mode, display mode, raw data mode etc., Win MTR has only two options data formats; txt and html data formats.

Linux MTR has the preference to identify which fields to be displayed and the order of the displayed fields which are separated by space characters for instance:

MTR -rw -o "DRAM" --aslookup www.gmail.com will display report wide data in the order of “DRAM” i.e. Dropped packets, Received packets, Average RTT/Delay and Jitter Mean/Avg

Basing on these specifics, it facilitated on the need to use Ubuntu Linux MTR tool for data collection. The raw data was collected from a total of 64 network connections.

The command used in linux MTR tool to capture the required dataset was;

MTR -rw -o "DRAM”; whereby:

“MTR” represents My Traceroute while “rw” denotes report wide mode.

"O" signifies report to be produced in the order of e.g., order of DRAM.

"DRAM" infers to Dropped packets, received packets, Average RTT/Delay and Jitter Mean/Avg respectively.

This information is not displayed by default but we can use the "o" option (or –order) to specify the order of the fields we want to grasp. The detailed field options are as follows:

```
-o FIELDS, --order FIELDS
       Use this option to specify which fields to display and in which order.  You may
       use one or more space characters to separate fields.
       Available fields:

                  +--+--------------------+
                  |L | Loss ratio         |
                  +--+--------------------+
                  |D | Dropped packets    |
                  +--+--------------------+
                  |R | Received packets   |
                  +--+--------------------+
                  |S | Sent Packets       |
                  +--+--------------------+
                  |N | Newest RTT(ms)     |
                  +--+--------------------+
                  |B | Min/Best RTT(ms)   |
                  +--+--------------------+
                  |A | Average RTT(ms)    |
                  +--+--------------------+
                  |W | Max/Worst RTT(ms)  |
                  +--+--------------------+
                  |V | Standard Deviation |
                  +--+--------------------+
                  |G | Geometric Mean     |
                  +--+--------------------+
                  |J | Current Jitter     |
                  +--+--------------------+
                  |M | Jitter Mean/Avg.   |
                  +--+--------------------+
                  |X | Worst Jitter       |
                  +--+--------------------+
                  |I | Interarrival Jitter|
                  +--+--------------------+
```

Figure 3.3: The available linux MTR field options

Example:

- MTR command to access gmail's Dropped packets, Received packets, Average RTT/Delay and Jitter Mean/Avg was accessed by below order of fields:

$ MTR -rw -o "DRAM" --aslookup www.gmail.com

Whereby:

MTR: Denoted for My Traceroute.

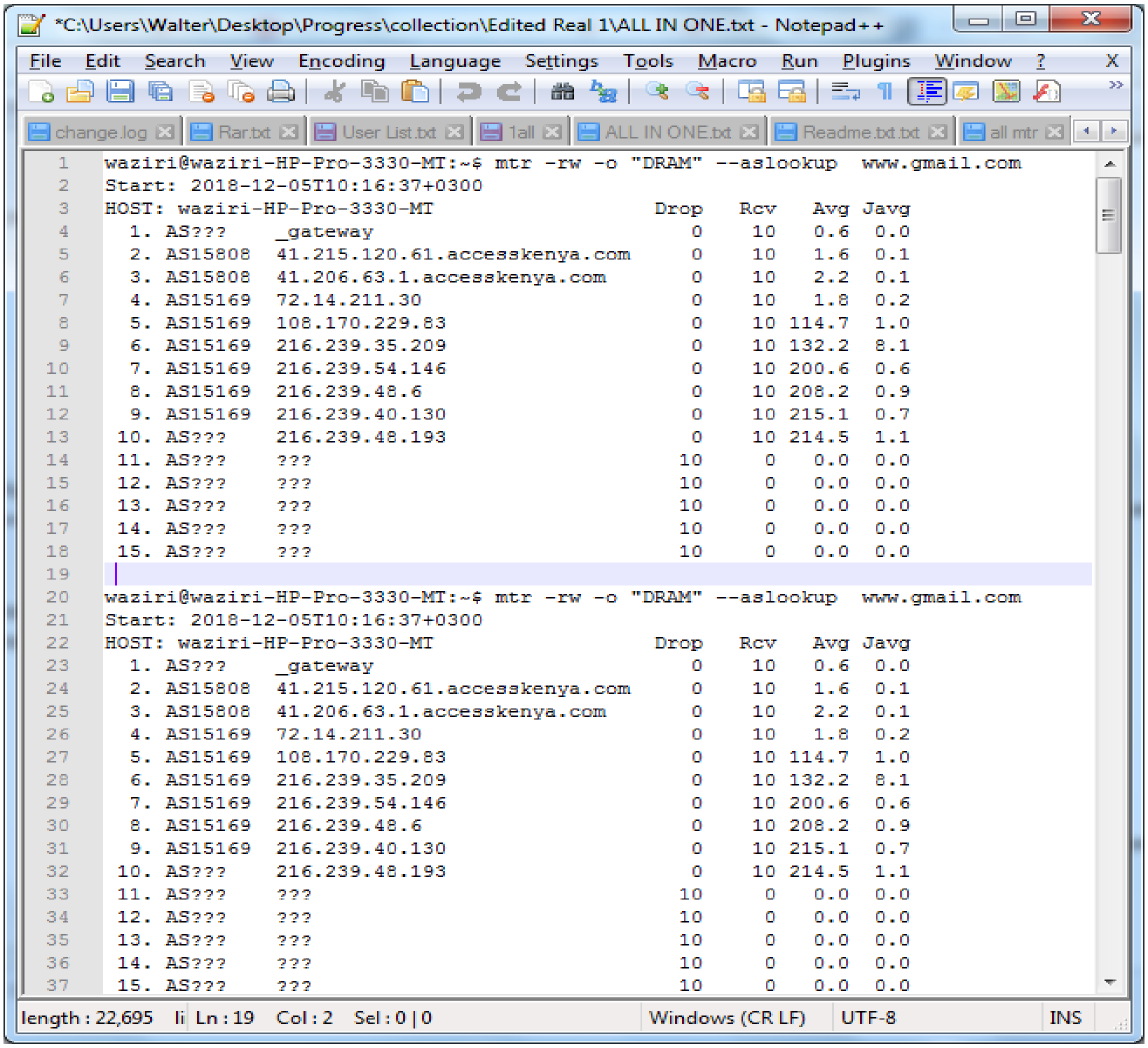
Rw: Signified Report wide mode.

O: Indicated the order of fields to be displayed, for instance –o "DRAM".

DRAM: Represented Dropped packets, Received packets, Average RTT/Delay and Jitter Mean/Avg respectively.

Aslookup: Was used to display Autonomous systems.

The discussed set of commands produced the following output dataset:



```
*C:\Users\Walter\Desktop\Progress\collection\Edited Real 1\ALL IN ONE.txt - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?
change.log  Rar.txt  User List.txt  1all  ALL IN ONE.txt  Readme.txt.txt  all mtr

waziri@waziri-HP-Pro-3330-MT:~$ mtr -rw -o "DRAM" --aslookup  www.gmail.com
Start: 2018-12-05T10:16:37+0300
HOST: waziri-HP-Pro-3330-MT                        Drop   Rcv   Avg  Javg
  1. AS???     _gateway                               0    10   0.6   0.0
  2. AS15808   41.215.120.61.accesskenya.com          0    10   1.6   0.1
  3. AS15808   41.206.63.1.accesskenya.com            0    10   2.2   0.1
  4. AS15169   72.14.211.30                           0    10   1.8   0.2
  5. AS15169   108.170.229.83                         0    10 114.7   1.0
  6. AS15169   216.239.35.209                         0    10 132.2   8.1
  7. AS15169   216.239.54.146                         0    10 200.6   0.6
  8. AS15169   216.239.48.6                           0    10 208.2   0.9
  9. AS15169   216.239.40.130                         0    10 215.1   0.7
 10. AS???     216.239.48.193                         0    10 214.5   1.1
 11. AS???     ???                                   10     0   0.0   0.0
 12. AS???     ???                                   10     0   0.0   0.0
 13. AS???     ???                                   10     0   0.0   0.0
 14. AS???     ???                                   10     0   0.0   0.0
 15. AS???     ???                                   10     0   0.0   0.0

waziri@waziri-HP-Pro-3330-MT:~$ mtr -rw -o "DRAM" --aslookup  www.gmail.com
Start: 2018-12-05T10:16:37+0300
HOST: waziri-HP-Pro-3330-MT                        Drop   Rcv   Avg  Javg
  1. AS???     _gateway                               0    10   0.6   0.0
  2. AS15808   41.215.120.61.accesskenya.com          0    10   1.6   0.1
  3. AS15808   41.206.63.1.accesskenya.com            0    10   2.2   0.1
  4. AS15169   72.14.211.30                           0    10   1.8   0.2
  5. AS15169   108.170.229.83                         0    10 114.7   1.0
  6. AS15169   216.239.35.209                         0    10 132.2   8.1
  7. AS15169   216.239.54.146                         0    10 200.6   0.6
  8. AS15169   216.239.48.6                           0    10 208.2   0.9
  9. AS15169   216.239.40.130                         0    10 215.1   0.7
 10. AS???     216.239.48.193                         0    10 214.5   1.1
 11. AS???     ???                                   10     0   0.0   0.0
 12. AS???     ???                                   10     0   0.0   0.0
 13. AS???     ???                                   10     0   0.0   0.0
 14. AS???     ???                                   10     0   0.0   0.0
 15. AS???     ???                                   10     0   0.0   0.0

length : 22,695   li  Ln : 19   Col : 2   Sel : 0 | 0   Windows (CR LF)   UTF-8   INS
```

Figure 3.4: MTR output in ubuntu linux platform

In the Figure 3.4 above, it displays detailed output results of executed MTR command.

In the report, individual named line denotes a network hop. Hops are nodes that network packets uses as a path to reach the endpoint. They are similarly denoted as network connections/autonomous systems initialized by “AS”.

In the case where we had **“AS???”** in the autonomous systems, it’s an indication that there was no further information about the network route or network packets being sent in a loop resulting from an effect of a router being configured poorly.

In some systems, using this flag requires administrative privileges to obtain output results. For instance, the below command is able to handle that in such a scenario:

Sudo MTR -rwc 50 –i 0.2 –rw 41.215.120.62

Whereby:

"r"**:** Report generation.

"w": --Report-wide mode for long-version of the hostname.

"c": Determines number of packets sent and noted in the output report. The default value is 10 if the value is not configured, for fast intervals the value can be set to a higher value though the report will take longer to load fully.

"i": Unveils packet loss taking place in the course of network congestion. It initiates MTR to transfer a packet for every n seconds. 1 second is the default value though to ensure the report takes shorter time to load fully, it can be configured to a fraction of a second.

Characterization of the data collection setup

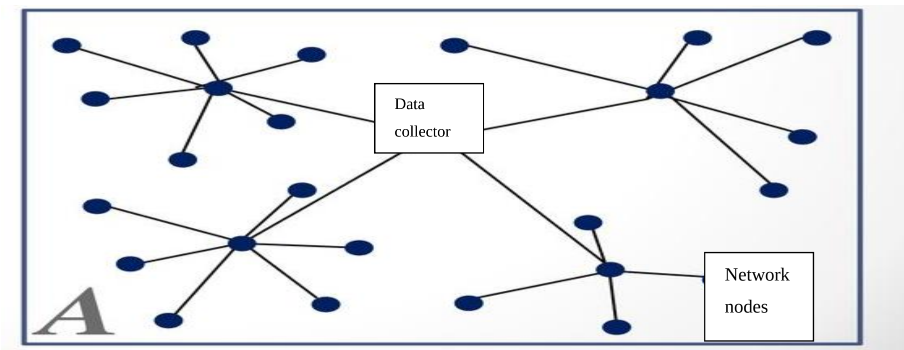


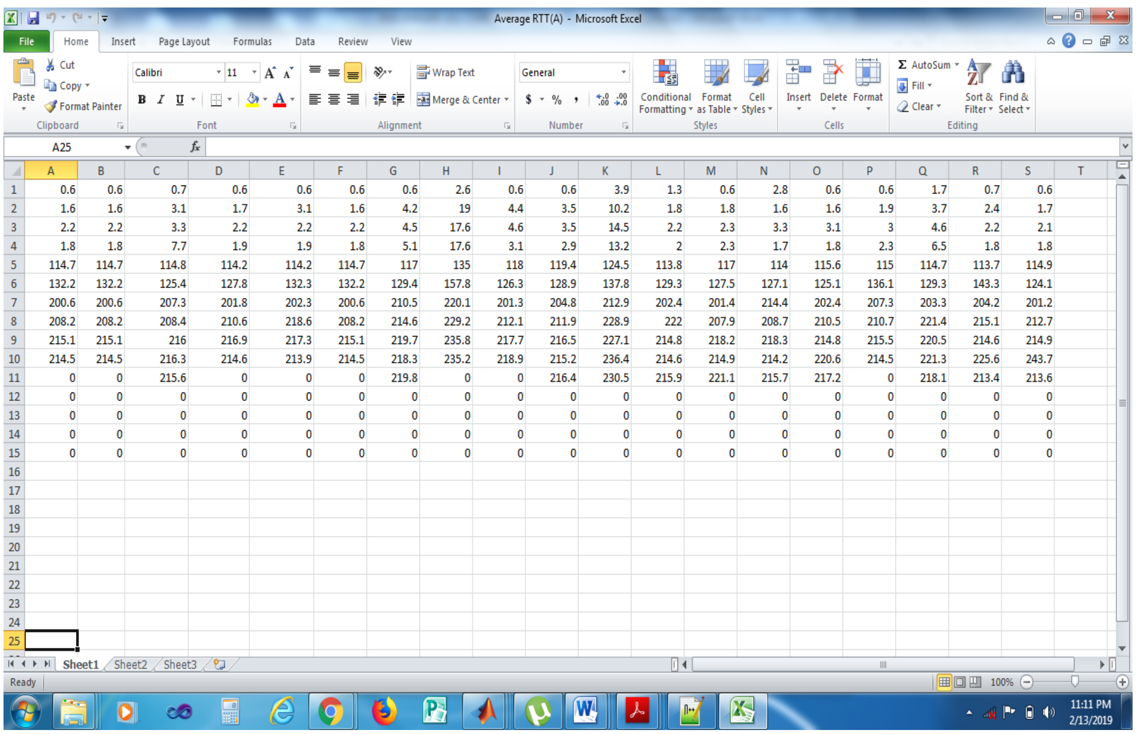
Figure 3.5: Characterization of the data collection setup

In Figure 3.5, the network nodes are the workstations connected to the LAN network. The data collector is the supercomputer used to collect the datasets from the LAN network, perform the data processing and network analysis.

3.8 Data processing and analysis

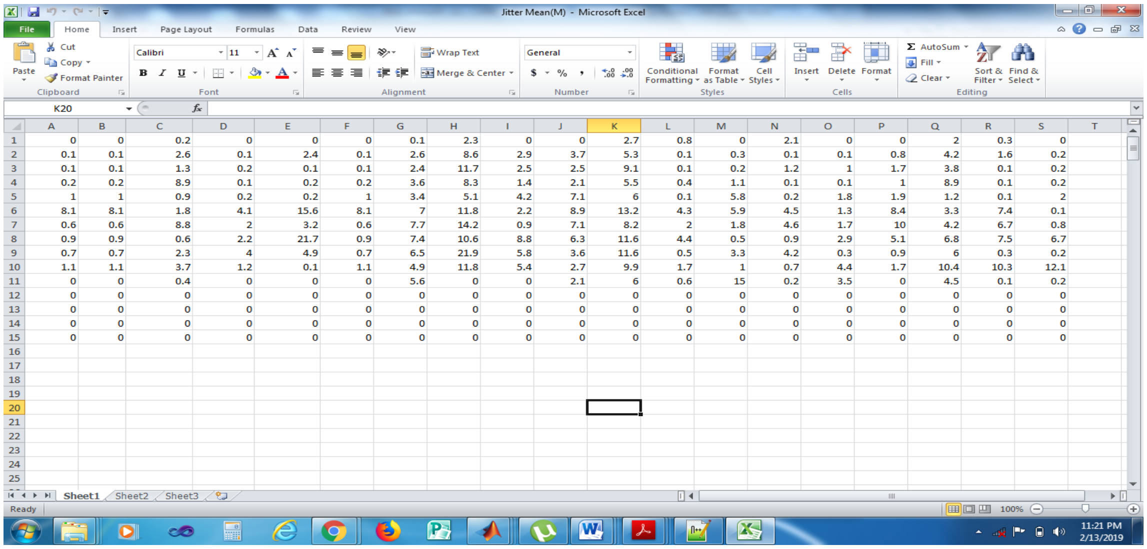
3.8.1 Ascertaining integrity of service parameters dataset: data cleaning

The acquired data from linux MTR tool was exported to Ms. Excel for cleaning/ processing. The processed data was presented in form of excel workbook format (.xlsx) each having crisp values for delay, jitter, packet loss, throughput and users dataset.



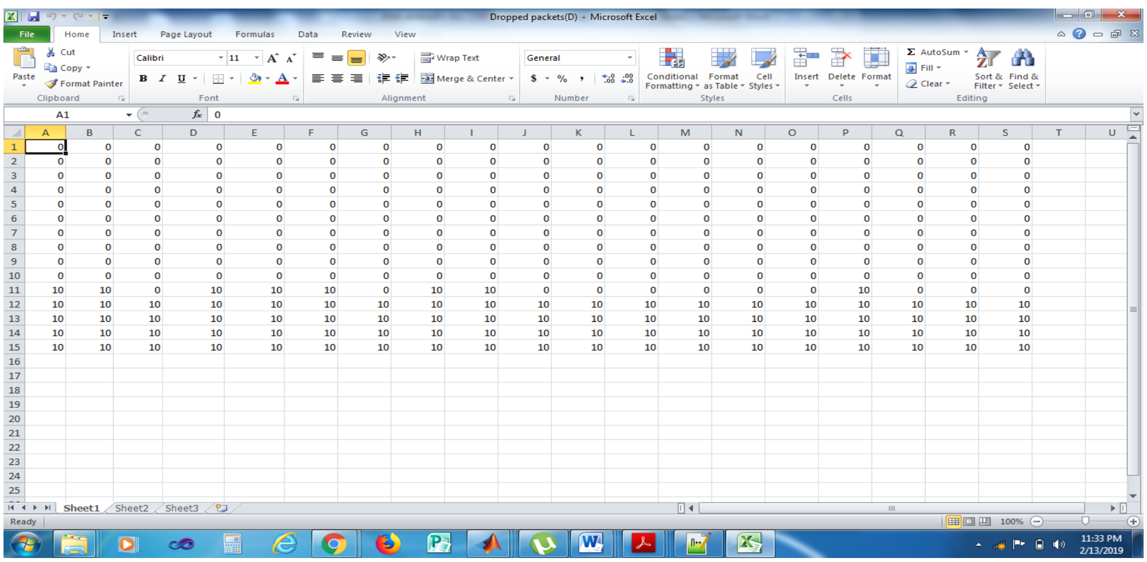
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	0.6	0.6	0.7	0.6	0.6	0.6	0.6	2.6	0.6	0.6	3.9	1.3	0.6	2.8	0.6	0.6	1.7	0.7	0.6
2	1.6	1.6	3.1	1.7	3.1	1.6	4.2	19	4.4	3.5	10.2	1.8	1.8	1.6	1.6	1.9	3.7	2.4	1.7
3	2.2	2.2	3.3	2.2	2.2	2.2	4.5	17.6	4.6	3.5	14.5	2.2	2.3	3.3	3.1	3	4.6	2.2	2.1
4	1.8	1.8	7.7	1.9	1.9	1.8	5.1	17.6	3.1	2.9	13.2	2	2.3	1.7	1.8	2.3	6.5	1.8	1.8
5	114.7	114.7	114.8	114.2	114.2	114.7	117	135	118	119.4	124.5	113.8	117	114	115.6	115	114.7	113.7	114.9
6	132.2	132.2	125.4	127.8	132.3	132.2	129.4	157.8	126.3	128.9	137.8	129.3	127.5	127.1	125.1	136.1	129.3	143.3	124.1
7	200.6	200.6	207.3	201.8	202.3	200.6	210.5	220.1	201.3	204.8	212.9	202.4	201.4	214.4	202.4	207.3	203.3	204.2	201.2
8	208.2	208.2	208.4	210.6	218.6	208.2	214.6	229.2	212.1	211.9	228.9	222	207.9	208.7	210.5	210.7	221.4	215.1	212.7
9	215.1	215.1	216	216.9	217.3	215.1	219.7	235.8	217.7	216.5	227.1	214.8	218.2	218.3	214.8	215.5	220.5	214.6	214.9
10	214.5	214.5	216.3	214.6	213.9	214.5	218.3	235.2	218.9	215.2	236.4	214.6	214.9	214.2	220.6	214.5	221.3	225.6	243.7
11	0	0	215.6	0	0	0	219.8	0	0	216.4	230.5	215.9	221.1	215.7	217.2	0	218.1	213.4	213.6
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3.6: Processed data for delay (A)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	0	0	0.2	0	0	0	0.1	2.3	0	0	2.7	0.8	0	2.1	0	0	2	0.3	0
2	0.1	0.1	2.6	0.1	2.4	0.1	2.6	8.6	2.9	3.7	5.3	0.1	0.3	0.1	0.1	0.8	4.2	1.6	0.2
3	0.1	0.1	1.3	0.2	0.1	0.1	2.4	11.7	2.5	2.5	9.1	0.1	0.2	1.2	1	1.7	3.8	0.1	0.2
4	0.2	0.2	8.9	0.1	0.2	0.2	3.6	8.3	1.4	2.1	5.5	0.4	1.1	0.1	0.1	1	8.9	0.1	0.2
5	1	1	0.9	0.2	0.2	1	3.4	5.1	4.2	7.1	6	0.1	5.8	0.2	1.8	1.9	1.2	0.1	2
6	8.1	8.1	1.8	4.1	15.6	8.1	7	11.8	2.2	8.9	13.2	4.3	5.9	4.5	1.3	8.4	3.3	7.4	0.1
7	0.6	0.6	8.8	2	3.2	0.6	7.7	14.2	0.9	7.1	8.2	2	1.8	4.6	1.7	10	4.2	6.7	0.8
8	0.9	0.9	0.6	2.2	21.7	0.9	7.4	10.6	8.8	6.3	11.6	4.4	0.5	0.9	2.9	5.1	6.8	7.5	6.7
9	0.7	0.7	2.3	4	4.9	0.7	6.5	21.9	5.8	3.6	11.6	0.5	3.3	4.2	0.3	0.9	6	0.3	0.2
10	1.1	1.1	3.7	1.2	0.1	1.1	4.9	11.8	5.4	2.7	9.9	1.7	1	0.7	4.4	1.7	10.4	10.3	12.1
11	0	0	0.4	0	0	0	5.6	0	0	2.1	6	0.6	15	0.2	3.5	0	4.5	0.1	0.2
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3.7: Processed data for jitter mean (M)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	10	0	10	10	10	0	10	10	0	0	0	0	0	0	10	0	0	0
12	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
14	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Figure 3.8: Processed data for packet loss/dropped packets (D)

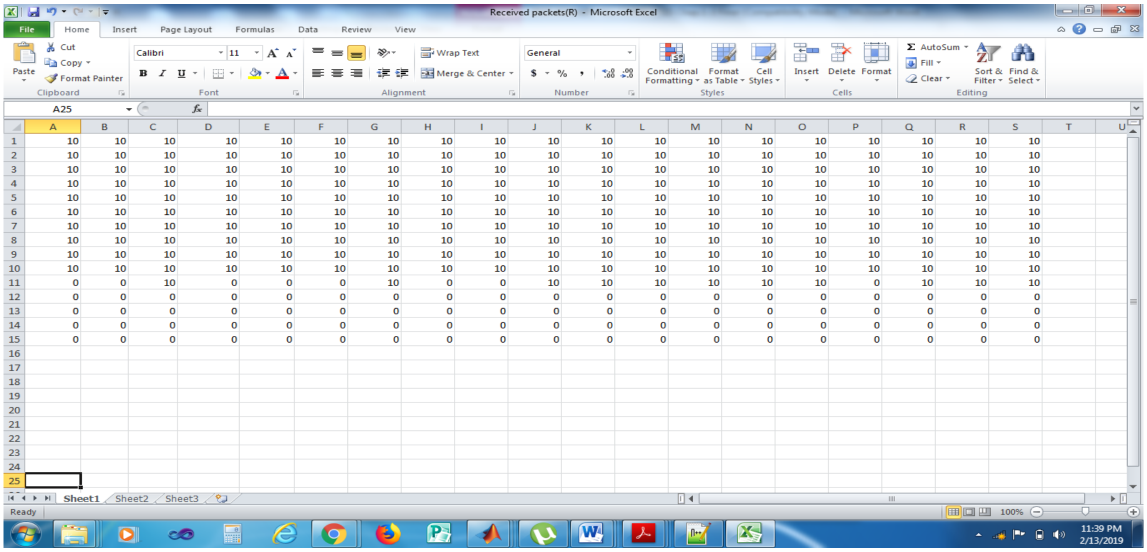


Figure 3.9: Processed data for received packets/throughput (R)

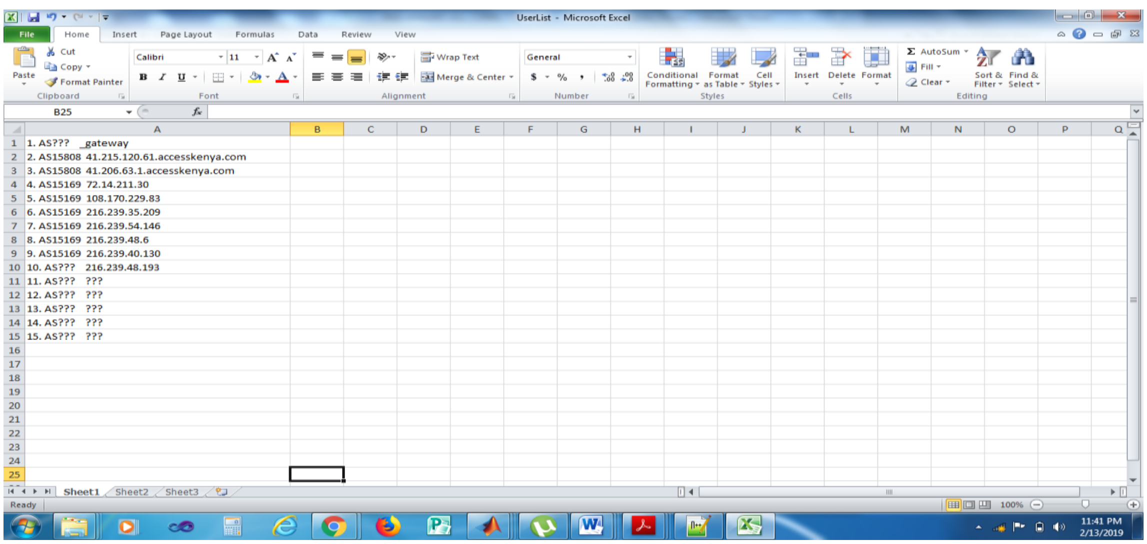


Figure 3.10: User list (autonomous systems/network connections)

The mean value data was used in MATLAB as crisp input data after performing the average. At this point is when the data underwent the transformation basing on the fuzzy logic methodology.

3.8.2 Designing fuzzy logic based QoE modeling architecture

Designing fuzzy logic based QoE modeling architecture was guided by fuzzy logic concept using MATLAB tool.

This phase performed the following activities: identification of; five input linguistic terms (low, very high, very low, high and medium), four input variables (delay, jitter, throughput and packet loss), five output linguistic terms (good, excellent, fair, bad and poor), designing triangular membership function for different linguistic terms, designing 625 fuzzy rules (5^4) i.e. input linguistic terms raised to the power of variables, which were later reduced to 240 logical rules in the four variable model for use in the experiment.

In this work, AND operator was used to aggregate the fuzzy set values in order to acquire the output.

In a nutshell, the design stage happened to design the below framework:

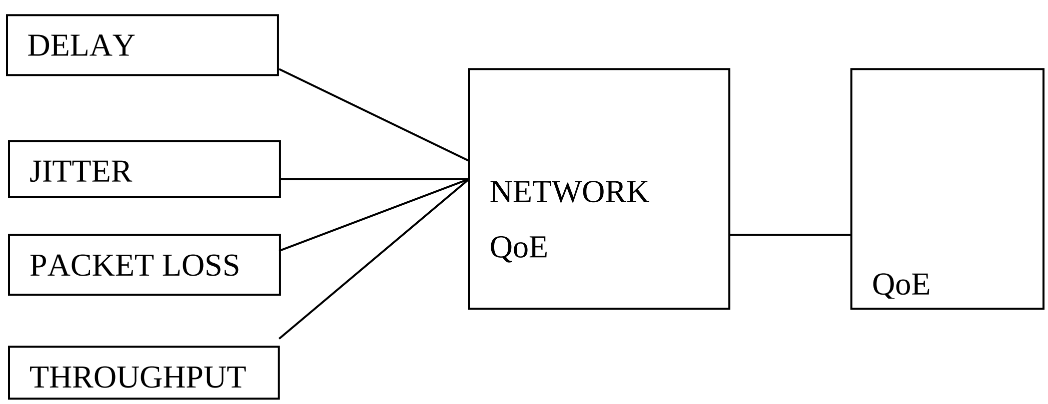


Figure 3.11: Designed network QoE framework

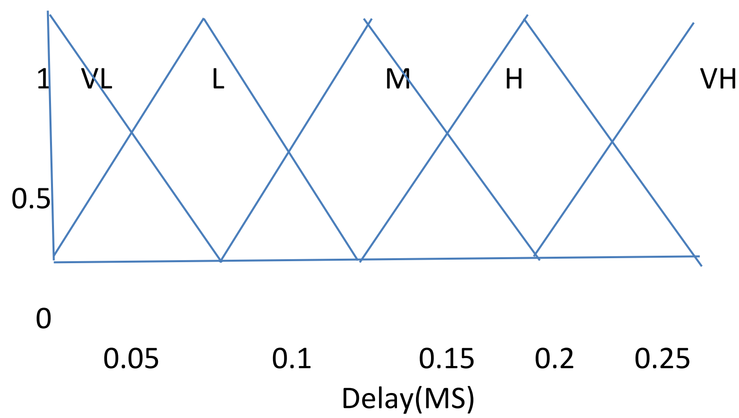


Figure 3.12: Designed triangular membership function for delay input linguistic term

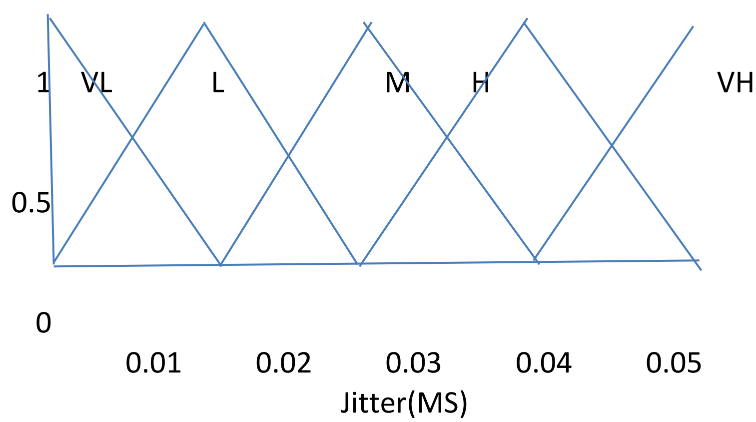


Figure 3.13: Designed triangular membership function for jitter input linguistic term

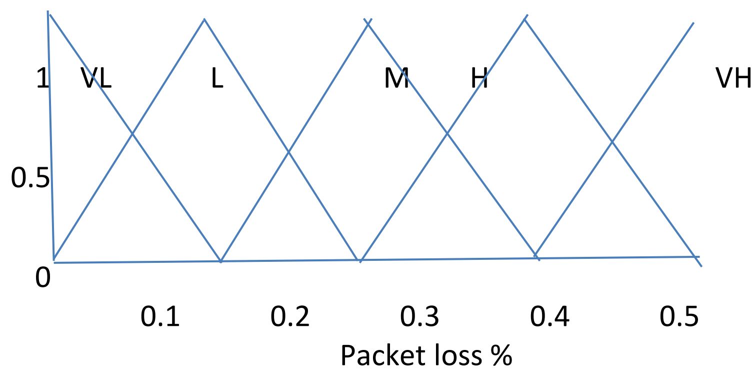


Figure 3.14: Designed triangular membership function for packet loss input linguistic term

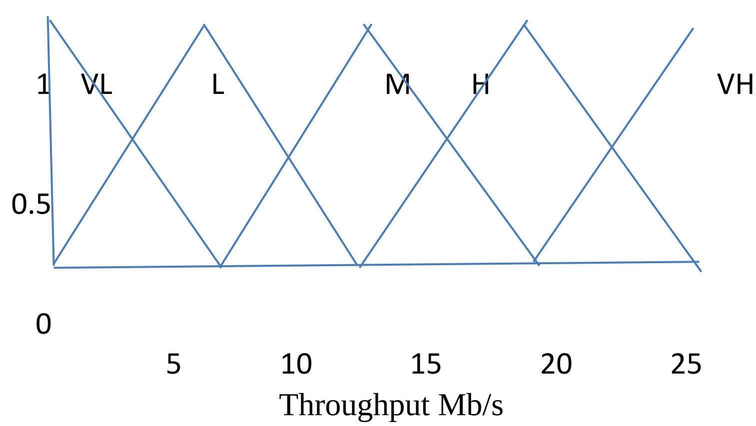


Figure 3.15: Designed triangular membership function for throughput input linguistic term

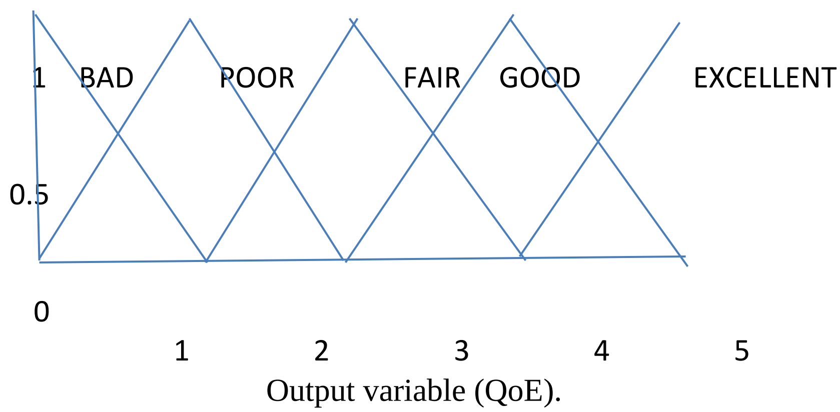


Figure 3.16: Designed triangular membership function for output linguistic terms

3.8.3 Developing fuzzy logic model for analysis of computer network QoE

This phase was guided through fuzzy logic approach. Acquired data from designed Linux MTR data capture experiment was used to make rational analysis based on the fuzzy rules and membership function in the developed model. The data was likewise utilized to assess the proposed improved four variables model performance in comparison with the two variables traditional model.

The development phase involved the following steps;

a. Defining the linguistic terms and linguistic variables under initialization phase.
b. Membership functions construction under initialization phase.
c. Rule base construction under the initialization phase.
d. Using membership functions to convert crisp input data to fuzzy values through fuzzification phase.
e. Rules evaluation in the rule base through inference phase

f. Singular rule results combination through inference phase.

g. Output data conversion to non-fuzzy values through defuzzification phase.

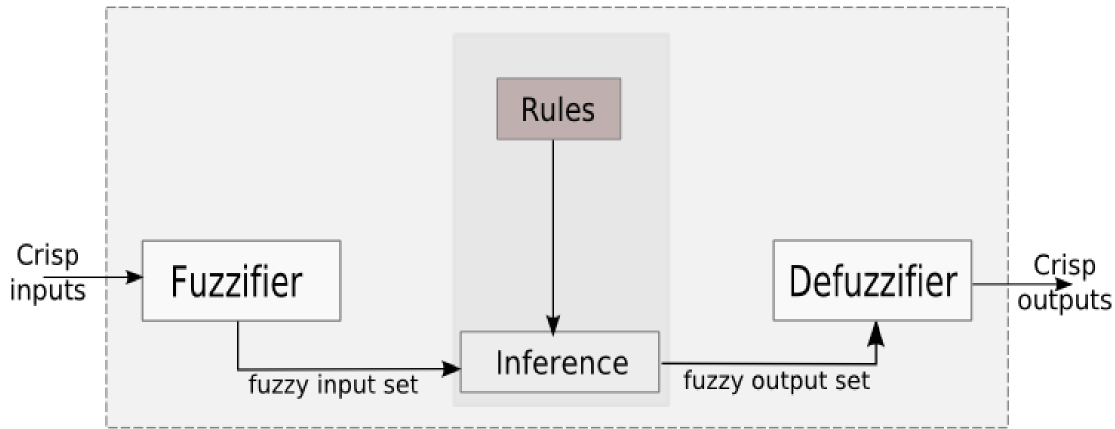


Figure 3.17: Fuzzy logic system (Singhala et al.,2015)

Initialization

This process involved defining the linguistic variables and terms. Five input linguistic terms were identified: Very low (VL), high (H), medium (M), very high (VH) and low (L). Five output linguistic terms were identified: Good, excellent, fair, bad and poor in reference to research work in (Pokhrel, 2015).

The input linguistic terms were arrived at grounding on (Farnaz, Seyed, & Ruan., 2014), whereby the operational ranges of network elements were set by means of the term sets i.e. Medium (M), very high (VH), very low (VL), high (H) and low (L) fuzzy membership functions thus enabling the incorporation of network service(s) indecision as well as dynamic forces altogether.

Likewise centering on (Zadeh L. , 1999), the progressiveness of fuzziness in human alleged manner recommends that considerable logic behind intellectual handling isn't based on two valued traditional logic or multivalued logic but on logic with fuzzy certainties. The concept of linguistic hedges was used to identify for each fuzzy linguistic term such as very low, very high and so on.

In relation to (Omar, Waweru, & Rimiru, 2015) , a function that modifies membership functions of fuzzy sets related to linguistic identifier, attaining a higher or lower accuracy subject on the occurrence is a linguistic hedge or linguistic modifier e.g. “very” and “more-or-less” are the famous modifiers.

In this phase, four variables for network integrity of service QoE parameters were identified: Packet loss, delay, jitter/delay variation and throughput. The identified variables are considered as primary factor for quality of service evaluation of any network (Yan et al., 2020)

The inter-relationship between the various QoE parameters and underlying QoS related parameters is illustrated in Table 2.1.

Constructing the membership functions (MF) was done at this stage. The process involved determining an arc defining each point in the input space mapping to the degree of membership (membership value) concerning 0 and 1 values.

In (Ascia, 2002), the most popular membership functions in use are:

i) Gaussian membership function (GMF)

ii) Triangular membership function (TMF).

The exponential assessment for Gaussian membership function is an unlimited sequence thus challenging to calculate. The series is trimmed for reduction of computational load resulting in enormous truncation errors (Ascia, 2002). Usage of lookup table is similarly not effective attributable to non-uniform spaces among e^{-n} values e.g. e^{-1}, e^{-2} and e^{-3} etc. This makes the look up table mapping nonlinear.

Likewise, to some extent permutation is a power of e thus addition concerning several lookup table data is complex. Main complication for its implementation is as a result of digital hardware being in powers of 2, while Gaussian membership function is declared as powers of e as discussed by (Ascia, 2002).

Degree of membership for linguistic terms utilized in this work was acquired by a triangular membership function. Triangular membership function is demarcated by upper limit "b", medium value "m" and lower limit "a" in that "a" is less than "m" is less than "b". At times Value "m – a" is equal to value "m – b", this is termed as b-m margin.

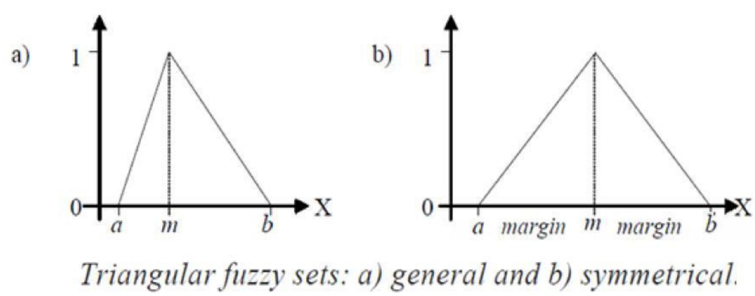


Figure 3.18: Triangular fuzzy set (zeynep, 2010)

The triangular membership equation can be reflected as in equation 3.1 (zeynep, 2010)

$$A(x) = \begin{cases} 0 & \text{if } x \le a \\ (x-a)/(m-a) & \text{if } x \in (a, m] \\ (b-x)/(b-m) & \text{if } x \in (m, b) \\ 0 & \text{if } x \ge b \end{cases}$$

Equation 3.1: The triangular membership equation

Alternatively, the triangular membership equation can be deliberated as in the equation 3.2 basing on (Ascia, 2002):

$$\mu(x) = \begin{cases} = \dfrac{x-a}{c-a} & \text{if } a \leq x \leq c \\ = \dfrac{b-x}{b-c} & \text{if } c \leq x \leq b \\ = 0 & \text{otherwise} \end{cases}$$

Equation 3.2: Alternative triangular membership equation

Membership value for triangular membership functions is simplified as:

The membership value μ(x) is a rating where input value "x" associates that membership and 0 is less than or equal to μ(x) while μ(x) is less than or equal to 1. Design considerations entails "C" as the center, "a" as left apex and "b" as right apex.

Trapezoidal and triangular membership functions are simple to implement thus facilitating simple calculations. Several research works proves that computational efficiency is the key factor in choosing the triangular membership function.

According to (Herbert, Thomas, & Manfred, 1996), triangular membership functions implementation is not complex thus facilitating computational efficiency. Smooth nonlinear membership functions (MFs) including bell, Gaussian MFs etc. experience computation difficulties due to exponential factors. Moreover, as a result of nonlinear plotting of functions, these membership functions are unsuitable for look-up table computation techniques. Similarly, computing hardware are in powers of 2, while nonlinear membership functions are declared as powers of e hence they cannot be easily implemented in low-end hardware.

Additionally, the initialization phase involved constructing the rule base. The identified five input linguistic terms for use i.e. "Medium", "Very high", "Very low", "High" and

“Low” inclusive of the Four input variables for network integrity of service QoE parameters i.e. Jitter/delay variation, packet loss, throughput and delay resulted into 5^4 factor thus 625 rules.

The resulting rules were further dropped centered on expert knowledge to 240 rules by discarding illogical rules thus remaining with logical rules to make rational decisions.

The illogical is as a result whereby some conditions cannot exist at the same time in an ideal situation. For instance in rule 1 of the 625 rules indicated:

1. If delay is “very low”, jitter is “very low”, packet loss is “very low” and throughput is “very low” then user satisfaction “N/A”.

This rule is N/A thus illogical since when packet loss, jitter and delay parameters are very low then throughput is supposed to be high or very high in ideal network situation as these three variables which are supposed to make the throughput very low, their existence too are very low not to certain levels to affect network throughput to match being very low.

Fuzzification

This phase involved utilizing membership functions to convert the crisp values for input data into fuzzy resultant values. FLS (fuzzy logic system) achieved this task by means of Fuzzifier component.

Primarily in this phase, a crisp set (subset elements of the set, definitely do belong to the set), of input data were assembled and transformed to fuzzy sets (sets whose elements have degrees of membership) through fuzzification consuming fuzzy linguistic terms, membership functions and fuzzy linguistic variables (Zadeh L. , 1965).

Integrity of service network quality of experience parameters was used: throughput, jitter/ delay variation, packet loss and delay. These acted as linguistic variables.

Inference

This stage involved evaluating the rules in the rule base. This was achieved by fuzzy inference system component of the fuzzy logic system. In this work, mamdani FIS (fuzzy inference system) was used to achieve inferencing in developed model.

The fuzzy set operator “AND” was utilized to comprehend each rule’s output.

The results of each rule were combined at this phase. The matched fuzzy rules were utilized in the defuzzification process.

The logical operator “AND” was selected for connecting the inputs in the experiment since it returns a false value (0) even when a distinct occurrence is false in an ideal situation (mathworks, 2019).For instance in the rule below:

If jitter is “very low”, packet loss is “very low”, delay is “very low” and throughput is “very high” then user satisfaction EXCELLENT:

In an ideal situation, when jitter, packet loss and delay are very low then throughput is very high as the network suffers no hitches thus resulting to user satisfaction being excellent.

Defuzzification of the output

The matched linguistic variables, linguistic terms, generated fuzzy rules and output results for each parameter were aggregated into one crisp value through defuzzification.

The model exploited five input linguistic terms: “very low”, “very high”, “medium”, “high” and “low” .The considered five output linguistic terms at this phase encompassed “excellent”, “good”, “fair”, “poor”, and “bad”. The output linguistic terms were quantified on a numerical scale on a range of 1 to 5 whereby the upper the value, the better the QoE and the lower the value the worse the QoE.

This process mapped a fuzzy set to a crisp set (Leekwijck & Kerre, 1999). The specified fuzzy sets and conforming membership degrees brought about a quantifiable crisp output value.

The defuzzifier component of a fuzzy logic system was utilized after inferencing phase whereby the resultant fuzzy value was defuzzified to attain the crisp value.

There are different methods to perform defuzzification including Max membership principle/height method, weighted average method/ center of area/centroid method/center of gravity, middle-of-maxima/ mean max membership, center of largest area/center of sums, first/ last of maxima etc. (Leekwijck & Kerre, 1999) .

Weighted average method technique was applied in this work. It’s molded as a result of weighting individual function in resultant output with corresponding largest membership value. Weighted average equation is shown in equation 3.3

$$z^* = \frac{\sum \mu_{\underset{\sim}{C}}(\bar{z}) \cdot \bar{z}}{\sum \mu_{\underset{\sim}{C}}(\bar{z})}$$

Equation 3.3: Weighted average equation (Zadeh L. , 1965)

Where **c** is the centroid, **μ (z)** is the membership function of the input (Zadeh L. , 1965).

Weighted average method graph:

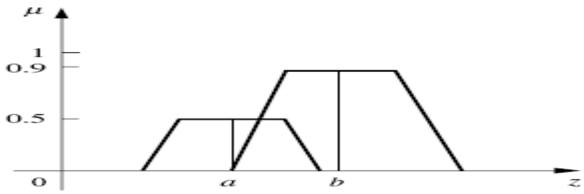


Figure 3.19: Weighted average method graph (Zadeh L. , 1965)

Weighted average defuzzification scheme is the most commonly used one in fuzzy logic applications because of its computational efficiency.

3.8.4 Evaluating the performance of proposed model with existing model

The proposed model was developed based on fuzzy logic methodology.

Basing on (Mnisi, Oyedapo, & Kurien, 2008), two important QoS parameters in computer networks are throughput and delay. Low levels of delay specifies great network performance thus high throughput.

Likewise, there was a necessity to include the entire four parameters associated with integrity of service for network quality of experience analysis i.e. jitter/delay variation, throughput, packet loss and delay. They are considered to be the primary factors affecting any computer networks (Farid et al.,2014).

In order to clarify this norm, there was need to develop two models for evaluation purposes based on the captured QoE value obtained: The first model had four variables i.e. throughput, jitter, packet loss and delay whereas the second model had two variables i.e. delay and throughput.

Data was first captured before being analyzed.The tools used included linux MTR tool for extraction of data, Ms. Excel executed data cleaning and data presentation. The cleansed Ms. Excel data files were used for valuation purposes. The evaluation was performed by means of two methods:

a) The rule viewer method in MATLAB

This method entailed noting the QoE values obtained both from the two models using same dataset combinations in MATLAB environment as demonstrated below. The obtained QoE values were further analyzed on comparison basis for best evaluation results.

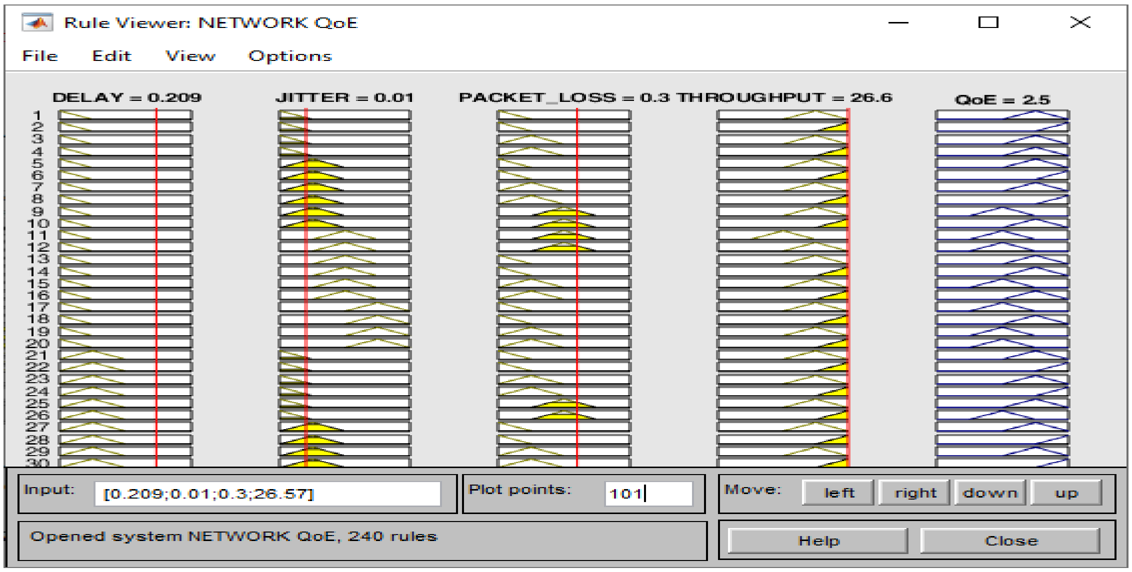


Figure 3.20: Analysis 1(a)

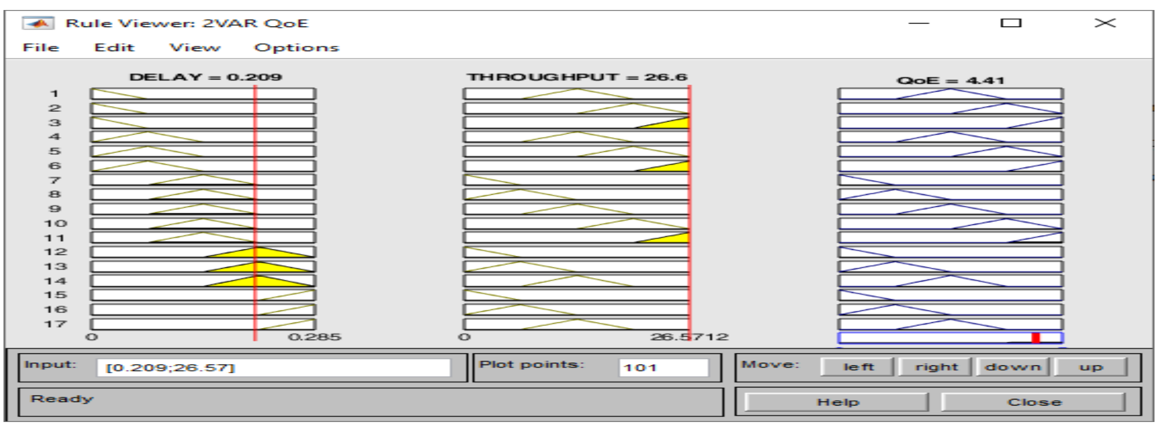


Figure 3.21: Analysis 1(b)

b) The independent T-test technique

Data was analyzed using independent samples T-test technique in order to determine the inevitability of either to use four integrity of service parameter compared to two integrity of service parameter when performing network QoE analysis.

SPSS tool was used to perform this method as clarified below systematically:

Data entry for analysis

Data was first captured before being analyzed. The tools used included linux MTR tool for extraction of data, Ms. Excel executed data cleaning and data presentation.

The cleansed Ms. Excel files were exported for analysis using independent T-test technique as demonstrated in the Figure 3.22 below:

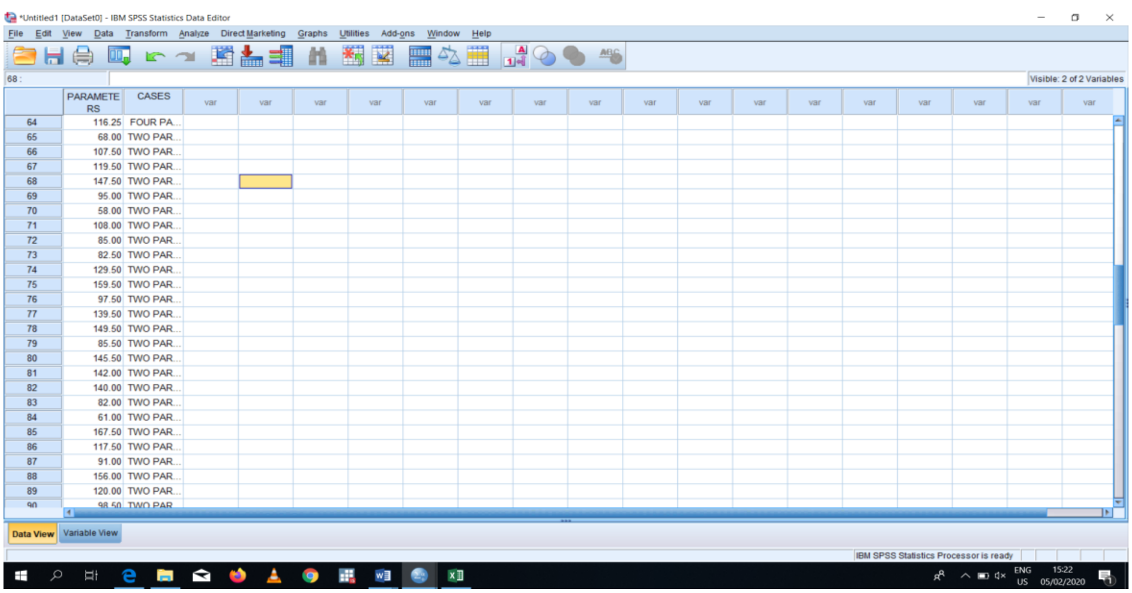


Figure 3.22: Data entry for analysis

Exploration of results

Data assessment was performed using independent sample T-test method for comparison of the two models mean performance in order to determine the inevitability of either to use four integrity of service parameter compared to two integrity of service parameter when performing network QoE analysis as illustrated below.

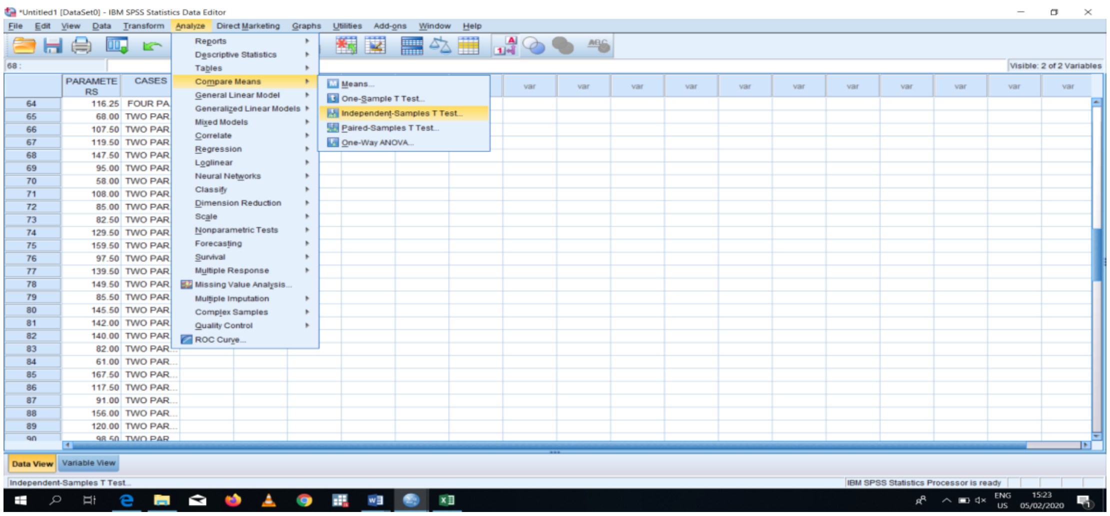


Figure 3.23: Statistics data analysis

Data was analyzed with the help of statistics data editor

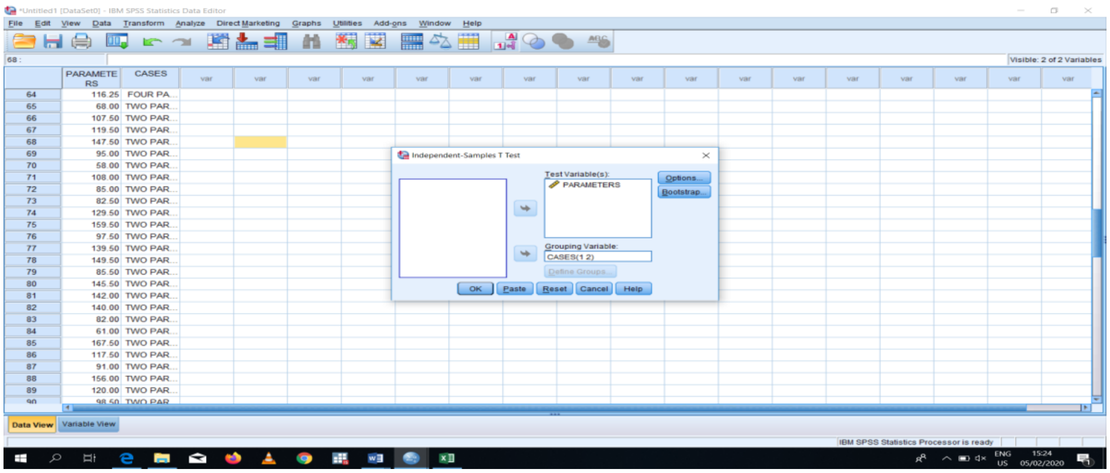


Figure 3.24: Statistics data editor

The below syntax command was executed to achieve the output results obtained:

```
T-TEST GROUPS=CASES(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=PARAMETERS
  /CRITERIA=CI(.95).
```

CHAPTER FOUR

RESEARCH RESULTS AND DISCUSSION

4.1 Introduction

This section covers data rendition directed by the adopted fuzzy logic approach and submission of outcomes. The outcome from the designed experiment influenced the deliberations as per research objectives.

4.2 The presentation of the data

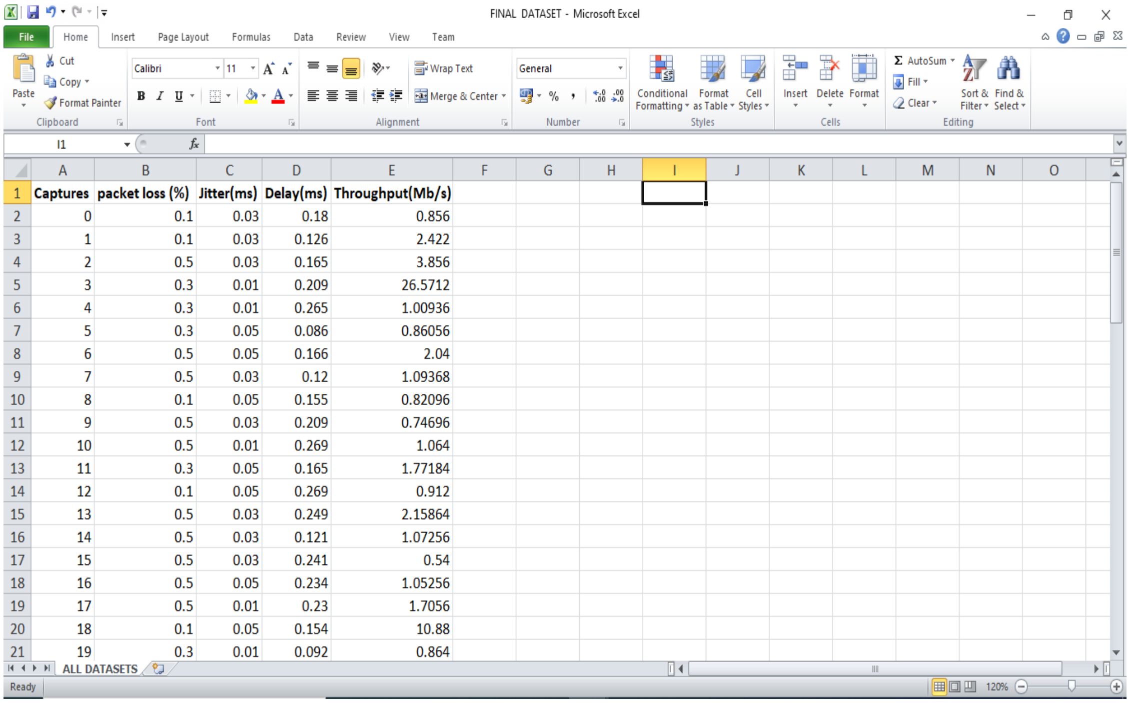
4.2.1 Ascertaining integrity of service parameters collected data: dataset

In the designed experiment, the processed data was presented in form of excel workbook format (.xlsx) each having crisp values for delay, jitter, packet loss, throughput and users' dataset.

Each column field of data from linux MTR tool was prearranged each on a different column in Ms. excel workbook for dataset usage.

This resulted to five columns in Ms. excel each having packet loss, throughput, delay, and jitter datasets as shown below. The extra column was used to indicate the captures/user list i.e. network connections/autonomous systems in the network.

The obtained crisp values for jitter, throughput, packet loss and delay were used as input dataset for analysis purposes.



Captures	packet loss (%)	Jitter(ms)	Delay(ms)	Throughput(Mb/s)
0	0.1	0.03	0.18	0.856
1	0.1	0.03	0.126	2.422
2	0.5	0.03	0.165	3.856
3	0.3	0.01	0.209	26.5712
4	0.3	0.01	0.265	1.00936
5	0.3	0.05	0.086	0.86056
6	0.5	0.05	0.166	2.04
7	0.5	0.03	0.12	1.09368
8	0.1	0.05	0.155	0.82096
9	0.5	0.03	0.209	0.74696
10	0.5	0.01	0.269	1.064
11	0.3	0.05	0.165	1.77184
12	0.1	0.05	0.269	0.912
13	0.5	0.03	0.249	2.15864
14	0.5	0.03	0.121	1.07256
15	0.5	0.03	0.241	0.54
16	0.5	0.05	0.234	1.05256
17	0.5	0.01	0.23	1.7056
18	0.1	0.05	0.154	10.88
19	0.3	0.01	0.092	0.864

Figure 4.1: Processed dataset

4.2.2 Resultant designed fuzzy logic based QoE modeling architecture

The design phase materialized the designing of a fuzzy logic based QoE modeling architecture. The designed architecture was utilized as a guiding principle for the entire research work activities based on fuzzy logic model as illustrated below:

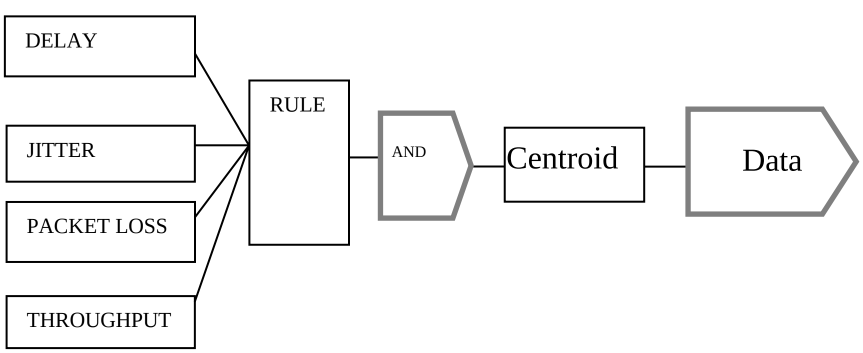


Figure 4.2: Architecture for fuzzy logic based QoE modeling

4.2.3 Improved fuzzy logic model for analysis of computer network QoE

The designed model was developed by use of fuzzy logic methodology. At this juncture, whatever was designed in the design phase was developed in MATLAB environment.

In this scenario, the captured crisp data were converted into fuzzy sets through fuzzification. Mamdani FIS was adopted to perform inferencing task. Obtained output fuzzy sets were further converted into a single crisp value through weighted average defuzzification technique. The acquired value was used to evaluate computer networks QoE analysis.

Mamdani was preferred compared to Sugeno and Tsukamoto FIS since it has sensitive power thus ability to approximate functions as clarified by (Abdelwahab & Nicolas D, 2008).

Mamdani has easy reinforcement and interpretability thus capable of being explained having realistic outcomes with moderately simple structure. Its inherent and explainable nature of the rule base makes mamdani FIS broadly utilized especially in decision support implementation as analyzed in (Muntaser & Nezar, 2018).

Mamdani FIS is broadly used in fuzzy modelling complications thus being implemented in this work since this research is based on model development as highlighted in (Fedor & Alex, 2020)

Moreover, mamdani FIS can be utilized in both MISO (multiple input single output) and MIMO (multiple input multiple output) systems thus can accommodate either fuzzy or a crisp output as deduced by (Geeksforgeeks, 2020).

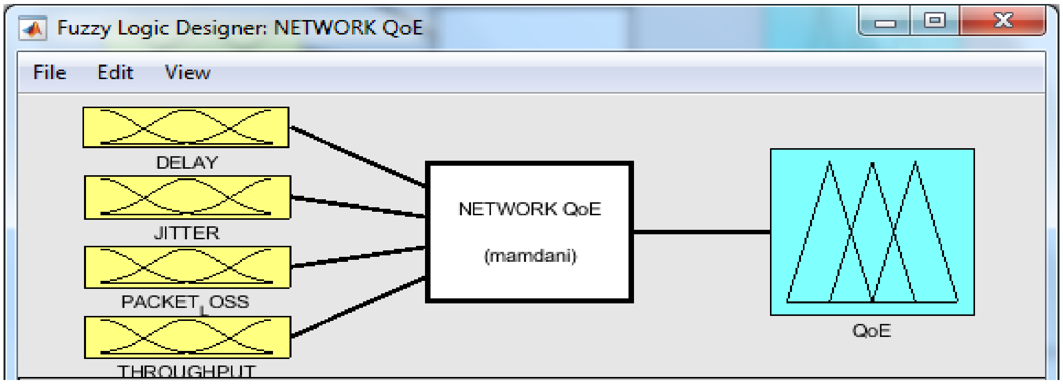


Figure 4.3: Developed network QoE model

Data range

The provided data interpretation of the variables values is in terms of ITU (International Telecommunication union) acceptable standards (ITU-T, 1996)

i) Degree of membership for input variables

a) Degree of membership for delay

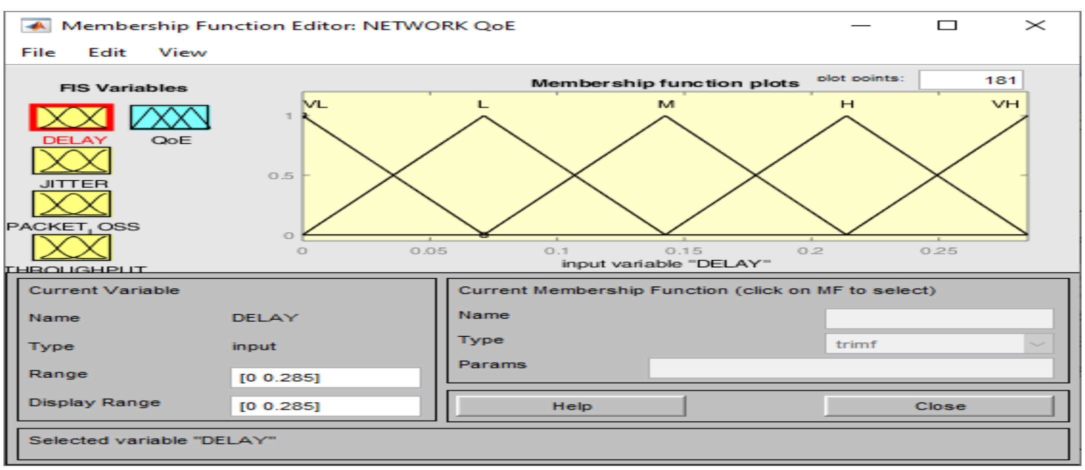


Figure 4.4: Triangular membership function plot for delay in MATLAB environment

The variable delay had a range of 0-0.285 milliseconds/MS.

Delay as a variable had membership function of very low (VL) having a range of values from [-0.07125 -1.013e-18 0.07125] milliseconds/MS whereby -0.07125 is the lowest value, -1.013e-18 is the mean value while 0.07125 is the highest value for this membership.

Membership function low (L) had a range of values from [0 0.07125 0.1425] milliseconds/MS whereby 0 is the lowest value, 0.07125 is the mean value while 0.1425 is the highest value for this membership.

Membership function medium (M) had a range of values from [0.07125 0.1425 0.2137] milliseconds/MS whereby 0.07125 is the lowest value, 0.1425 is the mean value while 0.2137 is the highest value for this membership.

Membership function high (H) had a range of values from [0.1425 0.2137 0.285] milliseconds/MS whereby 0.1425 is the lowest value, 0.2137 is the mean value while 0.285 is the highest value for this membership.

Membership function very high (VH) had a range of values from [0.214 0.285 0.356] milliseconds/MS whereby 0.214 is the lowest value, 0.285 is the mean value while 0.356 is the highest value for this membership.

b) Degree of membership for jitter

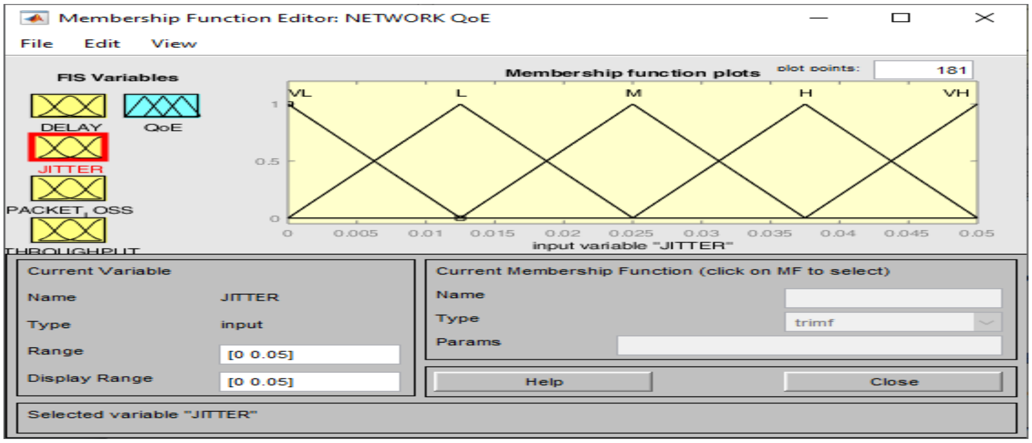


Figure 4.5: Triangular membership function plots for jitter in MATLAB environment

The variable jitter had a range of [0-0.05] milliseconds/MS.

Jitter as a variable had membership function of very low (VL) having a range of values from [-0.0125 0 0.0125] milliseconds/MS whereby -0.0125 is the lowest value, 0 is the mean value while 0.0125 is the highest value for this membership.

Membership function low (L) had a range of values from [0.000132 0.0126 0.0251] milliseconds/MS whereby 0.000132 is the lowest value, 0.0126 is the mean value while 0.0251is the highest value for this membership.

Membership function medium (M) had a range of values from [0.0125 0.025 0.0375] milliseconds/MS whereby 0.0125 is the lowest value, 0.025 is the mean value while 0.0375 is the highest value for this membership.

Membership function high (H) had a range of values from [0.025 0.0375 0.05] milliseconds/MS whereby 0.025 is the lowest value, 0.0375 is the mean value while 0.05 is the highest value for this membership.

Membership function very high (VH) had a range of values from [0.0375 0.05 0.0625] milliseconds/MS whereby 0.0375 is the lowest value, 0.05 is the mean value while 0.0625 is the highest value for this membership.

c) **Degree of membership for packet loss**

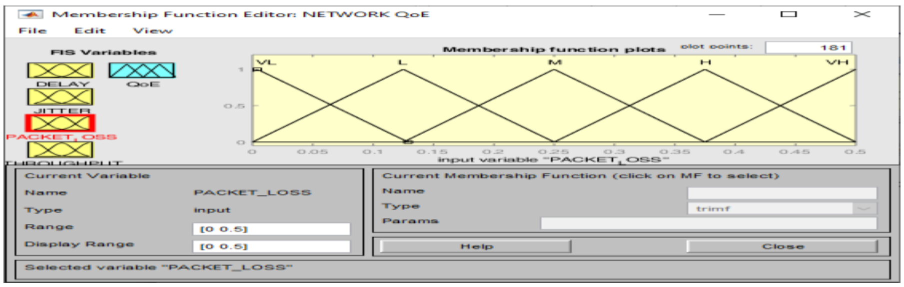


Figure 4.6: Triangular membership function plots for packet loss in MATLAB environment

The variable packet loss had a range of [0-0.5] %

Packet loss as a variable had membership function of very low (VL) having a range of values from [-0.121 0.003968 0.129] % whereby -0.121 is the lowest value, 0.003968 is the mean value while 0.129 is the highest value for this membership.

Membership function low (L) had a range of values from [0 0.125 0.25] % whereby 0 is the lowest value, 0.125 is the mean value while 0.25 is the highest value for this membership.

Membership function medium (M) had a range of values from [0.125 0.25 0.375] % whereby 0.125 is the lowest value, 0.25 is the mean value while 0.375 is the highest value for this membership.

Membership function high (H) had a range of values from [0.25 0.375 0.5] % whereby 0.25 is the lowest value, 0.375 is the mean value while 0.5 is the highest value for this membership.

Membership function very high (VH) had a range of values from [0.375 0.5 0.625] % whereby 0.375 is the lowest value, 0.5 is the mean value while 0.625 is the highest value for this membership.

d) Degree of membership for throughput

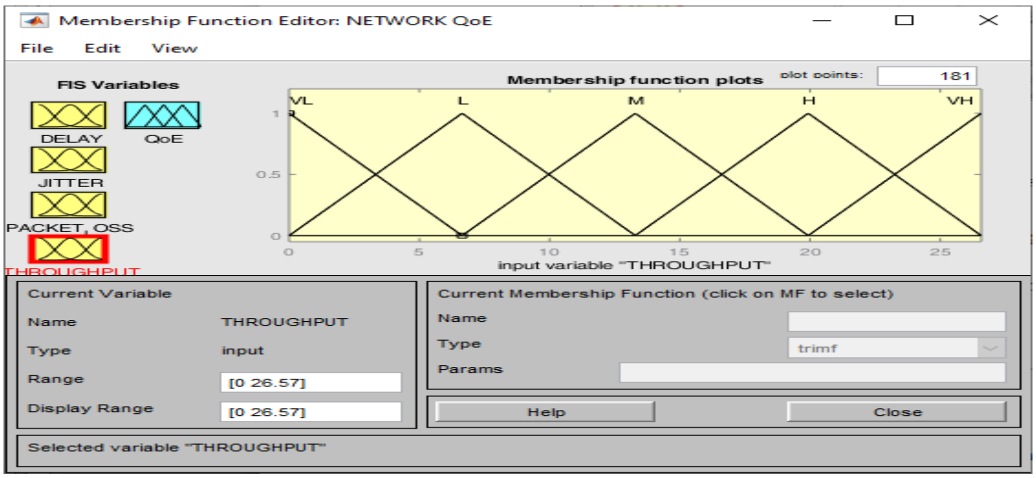


Figure 4.7: Triangular membership function plots for throughput in MATLAB environment

The variable throughput had a range of [0-26.57] megabits per second (Mbps)

Throughput as a variable had membership function of very low (VL) having a range of values from [-6.643 -7.376e-17 6.643] megabits per second (Mbps) whereby -6.643 is the lowest value, -7.376e-17 is the mean value while 6.643 is the highest value for this membership.

Membership function low (L) had a range of values from [0 6.643 13.29] megabits per second (Mbps) whereby 0 is the lowest value, 6.643 is the mean value while 13.29 is the highest value for this membership.

Membership function medium (M) had a range of values from [6.643 13.29 19.93] megabits per second (Mbps) whereby 6.643 is the lowest value, 13.29 is the mean value while 19.93 is the highest value for this membership.

Membership function high (H) had a range of values from [13.29 19.93 26.57] megabits per second (Mbps) whereby 13.29 is the lowest value, 19.93 is the mean value while 26.57 is the highest value for this membership.

Membership function very high (VH) had a range of values from [19.93 26.57 33.21] megabits per second (Mbps) whereby 19.93 is the lowest value, 26.57 is the mean value while 33.21 is the highest value for this membership.

ii) **Degree of membership for output variables**

a) QoE degree of membership

QoE as an output variable had range of values from 0-5 basing on mean opinion score values.

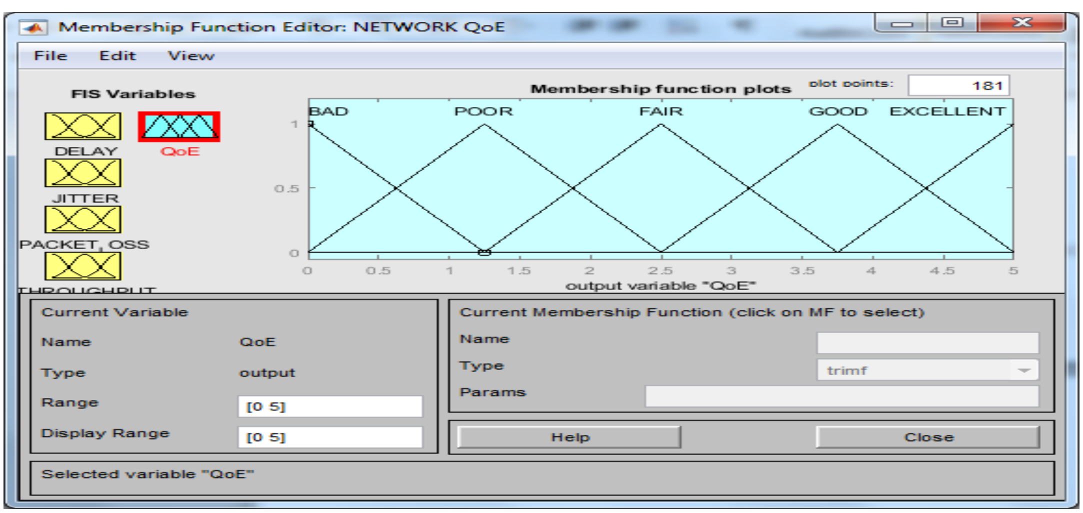


Figure 4.8: Triangular membership function plots for network QoE in MATLAB environment

The Output variable network QoE had a range of [0-5] ratings basing on mean opinion score (MOS) values.

QoE as an output variable had membership function of bad having a range of values from [-1.25 0 1.25] whereby -1.25 is the lowest value, 0 is the mean value while 1.25 is the highest value for this membership.

Membership function poor had a range of values from [0 1.25 2.5] whereby 0 is the lowest value, 1.25 is the mean value while 2.5 is the highest value for this membership.

Membership function fair had a range of values from [1.25 2.5 3.75] whereby1.25 is the lowest value, 2.5 is the mean value while 3.75 is the highest value for this membership.

Membership function good had a range of values from [2.5 3.75 5] whereby 2.5 is the lowest value, 3.75 is the mean value while 5 is the highest value for this membership.

Membership function excellent had a range of values from [3.75 5 6.25] whereby 3.75 is the lowest value, 5 is the mean value while 6.25 is the highest value for this membership.

The development phase was further realized by the help of “guide” command in MATLAB in order to develop a graphical user interface (GUI).The command prompted for an option to either create GUI or opening an existing GUI. In this scenario, there was need to create a new GUI. The built GUI was saved into the selected folder resulting into two file formats i.e. .fig (to access the underlying objects in the figure) and .m file formats (to indicate MATLAB code is in files with extension .M)

The use of “guide” command attained a graphical user interface (GUI) that facilitated users to perform network QoE analysis based on the keyed data as shown below:

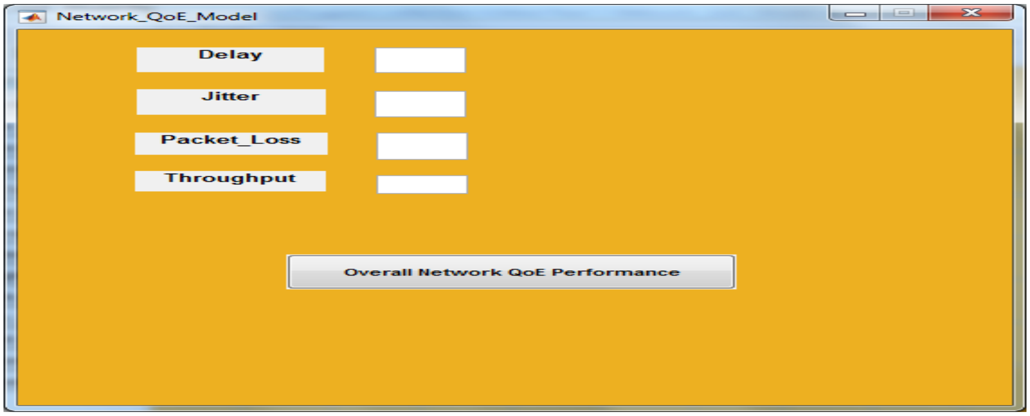


Figure 4.9: Developed application

4.2.4 Evaluating the performance of the model

To evaluate the model we used the following methods:

a. Independent T-test technique to determine the mean performance of the models.
b. Rule viewer method based on the obtained QoE values for both the models in MATLAB rule viewer environment when using same dataset in each scenario.

Independent T-test technique results

The below command was executed to achieve the output results obtained

```
T-TEST GROUPS=CASES(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=PARAMETERS
  /CRITERIA=CI(.95).
```

Whereby the "T-TEST GROUPS" had two "CASES" of comparison i.e. between case 1(Four variables model) and case 2 (Two variables model). The "VARIABLES" were the network parameters. The "CRITERIA" used was confidence interval (CI) of 95% which was equivalent to 0.95 when converted to whole number.

The obtained results in the Figure 4.10 below revealed that there is noteworthy difference in mean performance between four parameters and two parameters' models since the p value identified by sig (2-tailed) column in the Figure 4.10 was 0.017 which is less than 0.05 as the confidence interval (CI) was 0.95. The analysis identified the need for the entire four network parameters when performing network QoE analysis for best performance.

Group Statistics

	cominations	N	Mean	Std. Deviation	Std. Error Mean
values	Two combined	128	1.4518991	2.94874396	.26063461
	four combined	256	.8118870	2.18141602	.13633850

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
values	Equal variances assumed	5.445	.020	2.400	382	.017	.64001203	.26664831	.11572986	1.16429420
	Equal variances not assumed			2.176	198.606	.031	.64001203	.29414042	.05997288	1.22005118

Figure 4.10: Analysis statistics for independent samples-Test

The analysis was into two sections as output results i.e. group statistics and independent samples test.

Group statistics offered basic group comparisons. It determined the sample size (N), the mean, the standard deviation and the standard error mean for the network data summarized as a group.

In this scenario, there were 128 sample size (N) dataset for the two variables model and 256 sample size (N) dataset for the four variables model. The mean value for the two variables model was 1.4518991 while the mean value for the four variables model was 0.8118870.

The “Independent Samples Test” section presented the outcomes utmost appropriate to independent samples T test. This section had two portions that delivered diverse quantities of data including the “Levene’s Test for Equality of Variances” and “t-test for Equality of Means.”

The “Levene’s Test for Equality of Variances” administered the assumed analysis results whereby “F” was the test statistic of Levene's test manifested as 5.445 in this case.

Sig. was the assumed p-value corresponding to this dataset marked as 0.020.

The sig. i.e. p-value of Levene's test marked as 0.020 is read as $p<0.05$ i.e. $p<a$, therefore we concluded that the variance in values of four variables model is significantly different than that of two variables model thus pointing towards using "Equal variances assumed" row values for obtaining the t test value and its respective confidence interval outcomes.

The “t-test for Equality of Means” section delivered the concluded outcome for the actual independent samples T-test whereby:

“t” was the measure of test statistic marked as 2.400, “df ” indicated the degrees of freedom manifested as 382, “Sig (2-tailed)” indicated the actual p-value corresponding to the given dataset and degrees of freedom manifested as 0.017.

The “Mean Difference” was the difference between the samples means marked as 0.64001203.

The “Std. Error Difference” was the standard error denoted as 0.26664831.

The “Confidence Interval of the Difference” section supplemented the significance assessment effect. In this scenario, the 95% confidence interval i.e. CI was utilized resulting into 0.11572986 as the lower limit and 1.16429420 as the upper limit of this interval which has no zero value thus agreeing with the p-value of significance assessment.

Rule viewer method

This technique was achieved through comparison of both the two models results obtained from MATLAB rule viewer. In order to clarify the analysis, there was need to develop two models to capture the QoE value obtained using input data captured by linux MTR tool from the designed experiment: the four variables model (jitter, delay, throughput and packet loss) and the two variables model (delay and throughput) as validated below:

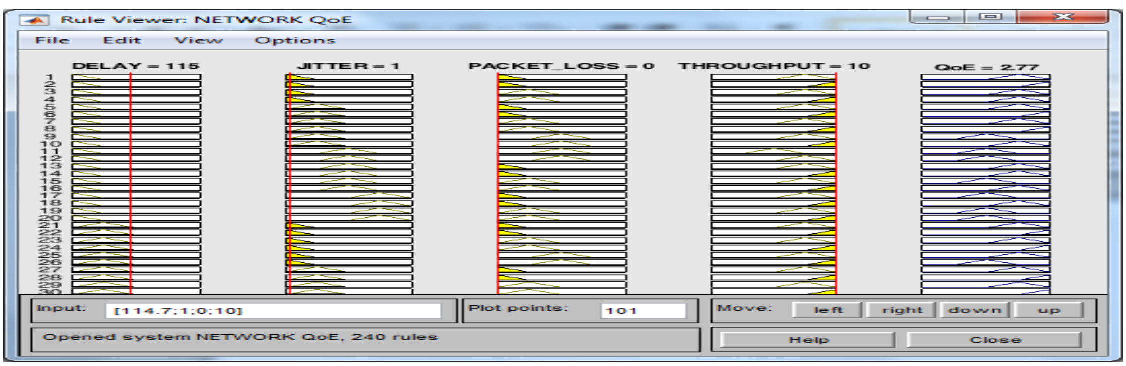


Figure 4.11: Analysis 1(a)

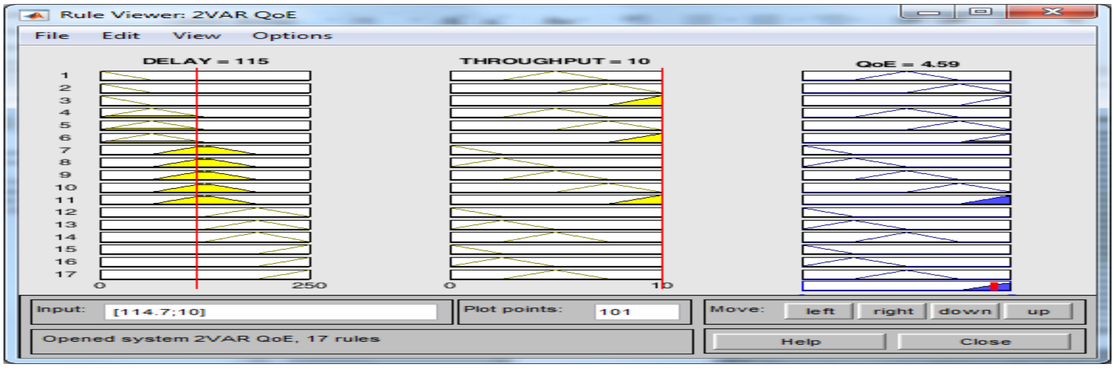


Figure 4.12: Analysis 1(b)

When the models were evaluated using the output QoE values, it was noted that there was a difference in QoE values obtained for analysis. Basing on the captured data from the designed experiment using linux MTR tool, when delay is 115MS, Jitter is 1MS, packet loss is 0% and throughput is 10 mb/s, the QoE value in the model consisting of four variables tends to produce a MOS of 2.77, while when the same dataset used for delay of 115MS and throughput of 10 mb/s being used in the model consisting of two variables (delay and throughput) it tend to produce a MOS of 4.59. The jitter and packet loss values tend to have a significant effect for analysis of network QoE thus excluding them may not provide a clear analysis of network QoE as the output MOS value dropped when the model had four variables while the value raised when the model had two variables.

In this comparison, evidently it indicated that there is a necessity to include all the four parameters which are linked to the integrity of service (throughput, delay, packet loss and delay variation/jitter) ever since they are considered to be the primary factors affecting any computer networks (Farid et al.,2014).

Framework tools that were needed for requirement analysis and system design

Requirements analysis generally involved establishing what the user(s) required from a software system/model. It involved two types: non-functional requirements and functional requirements.

Non-functional requirements:

Nonfunctional requirements embraced the features that must be possessed by the model. They make the model eye-catching, operational, fast in actions and dependable. They necessitate styling of the product implementation in anticipated way but they are not part of the vital purpose for its existence. They included:

a. User-friendliness: The model had the capability to provide decent and easy to use software interface thus easy to learn and use.
b. Extensibility: The model had the proficiency of being designed to allow the addition of new capabilities or functionality into the model to embrace other sub attributes of software system for instance ability to support additional Underlying QoS-related parameters under different QoE parameters including Accessibility, retain ability and integrity of service for efficiency purposes.
c. Scalability of the system: The model was designed to support additional users/autonomous systems (AS) in order to acquire the best analysis basing on a wide range of data to be analyzed from various users/autonomous systems (AS).
d. Document ability: The phases of the model development were well documented whereby the documentation contained the user manual for the model for instance use case diagram, Activity diagram etc.
e. Evolve ability: The developed model has the aptitude to exploit new technologies that enables the model to respond effectively to users' request, being portable to any platform with minimal modifications on it etc.

Functional requirements:

These requirements identify exactly what must be done by the product. They are fundamental reasons for the product's existence. The major identified functional requirements for this model included:

a. The model represented the entire four computer network underlying QoS-related parameters i.e. Jitter, throughput, packet loss and delay which lie under integrity of service quality of experience (QoE) parameters.
b. The model evaluated the network QoE performance based on the four variables: Jitter, throughput, packet loss and delay.
c. The model performed network analysis of the identified variables based on fuzzy logic methodology.
d. The model outputs the QoE value depending on the keyed crisp values data of the network variables i.e. Jitter, throughput, packet loss and delay captured from the experiment.
e. The model provided graphical user interface for interaction with users to feed in input values and acquire output results in return.

Unified modeling language (UML diagrams)

UML (unified modeling language) diagram is a graphical semantic for picturing, identifying, creating and detailing the objects of a software system (Bharath, 2012). Bharath (2012) outlined unified modeling language diagrams into two views:

i) Structural/ static view

It emphasized on the structure of the model that is fixed by means of entities, characteristics, activities and associations for instance class diagram.

ii) Behavioral/dynamic view

It emphasized the changing factor of the model by initiating relationships between objects and modifications to objects' internal condition and contents for instance activity diagram, sequence diagram etc.

How UML was used for model design and development

UML was used as an outline to interconnect system's phases in various ways:

UML was used for documentation i.e. changes made to the system were first realized on paper. Similarly, it acted as a blueprint whereby it provided a design plan of the model to be implemented. Moreover, it was in use for forward or backward design for doing UML before or after coding respectively.

4.9.1: Use case diagram

It's the model's functionality in terms of actors, their goals and needs among use cases (Bharath, 2012).

The use case in this scenario described relations concerning users and the developed model. The use case analysis is the foundation upon which the model was built. Based on the developed model, the following use case was attained as shown below:

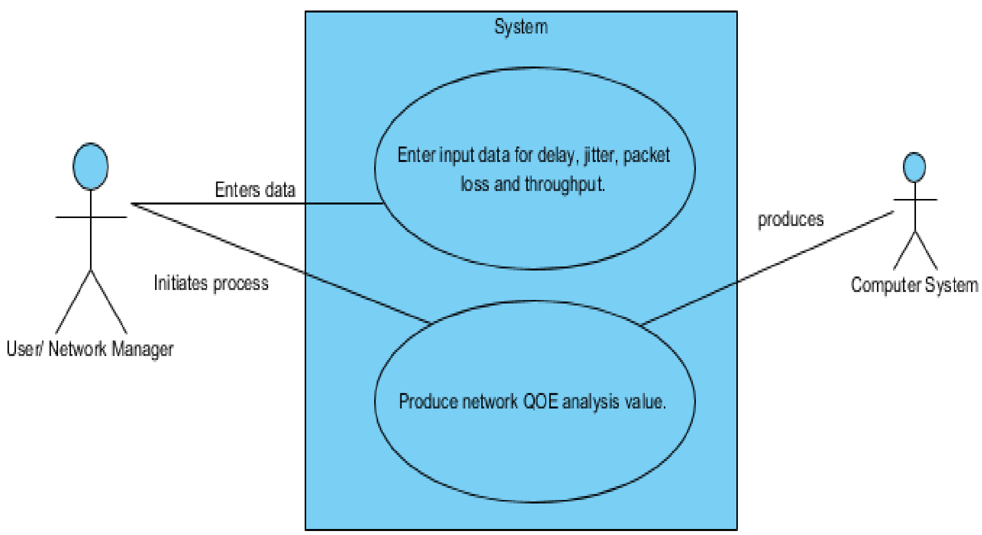


Figure 4.13: Use case diagram

4.9.2 Class diagram

The class of network QoE parameters was identified as the parent class with sub characteristics forming the child classes as shown in the diagram below. The attributes of the class were name(s) and/or value(s). Methods and activities incorporated: Input value, display value, analyze value, provide details, view results and get value. Correspondingly, a class network manager/user was identified ever since is responsible to provide details/data to the class network QoE parameters to be analyzed with a one to many relationship to the class integrity of service QoE parameters as shown below:

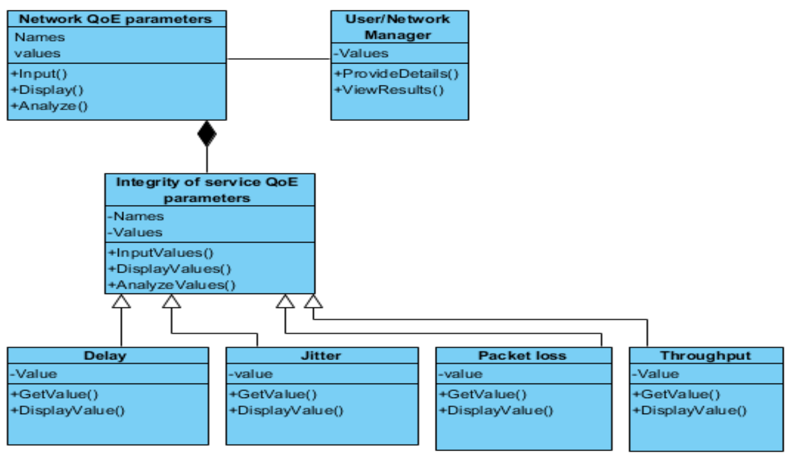


Figure 4.14: Class diagram

4.9.3 Activity diagram

This diagram basically aided in focusing on movements determined by internal processes as shown below:

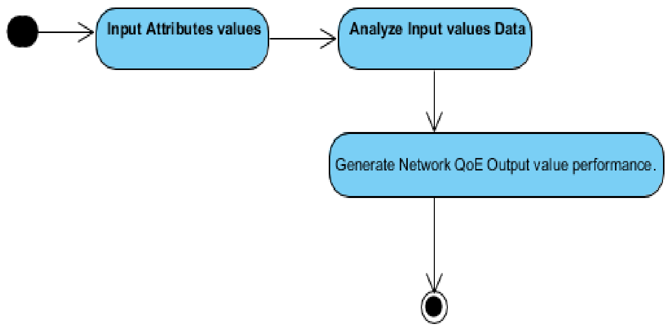


Figure 4.15: Activity diagram

4.9.4 Sequence diagram

This diagram demonstrated objects' activities in use case(s) by outlining the items and passed messages. The diagram is read downwards from top to bottom in a left to right manner. Likewise the diagram described connections among classes in relation to message exchange. This aided to know how messages streamed within the model.

The sequence diagram generated is as shown below.

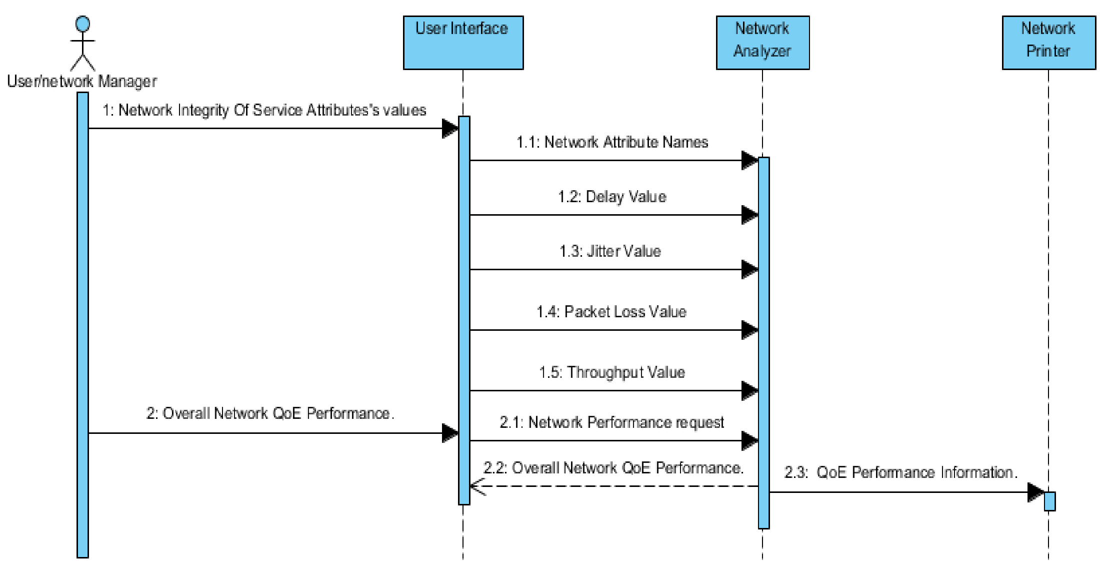


Figure 4.16: Sequence diagram

4.9.5 Package diagram

This diagram depicted the various model suites as shown below. They include network performance numerical engine used to analyze the quality score and generate tendencies for various network parameters identified in the model. The network QoE performance attribute evaluator was used to assess the individual QoE attributes for the model.

The processed information generator was used to produce reports for the overall QoE score for the entire developed model.

The network QoE analysis model interface was used to provide interaction to the model by users.

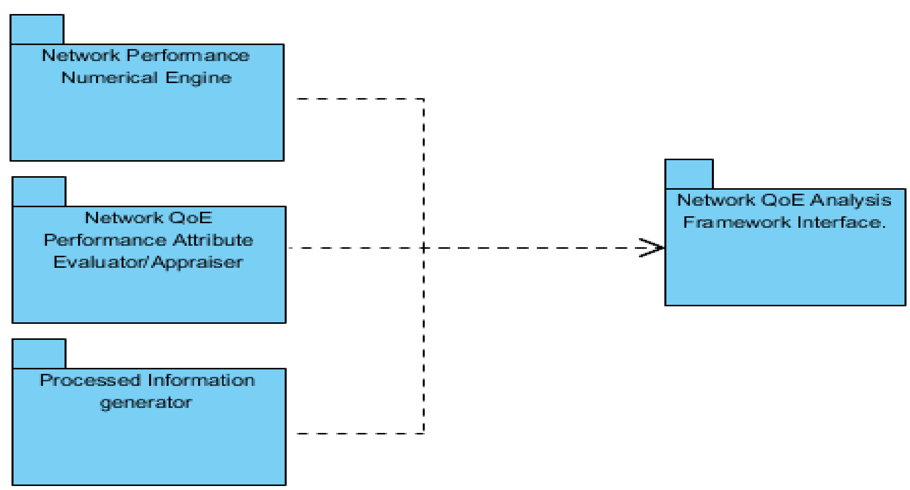


Figure 4.17: Package diagram

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

5.1 Introduction

This section covers knowledge contribution to the field of study, limitations of the study, recommendations/future work and conclusion.

5.2 Knowledge contribution to the field of study

In general, this research work achieved the following:

- Developed a four-parameter model based on integrity of service four parameters namely: Throughput, delay, packet loss and jitter. Fuzzy logic methodology was implemented using experimental research design. Five input linguistic terms were utilized: High, very high, medium, very low and low. Five output linguistic terms were used to refer to the opinion scores: Bad, poor, fair, good and excellent.
- Data collection using linux MTR tool for use in the experiment. In this work we collected the data from a local area network of 64 nodes for the four parameters, namely: Throughput, delay, packet loss and jitter. Inferencing to this work, it was strongly evidenced that linux MTR as one of the best tools for this purpose as it implements the functionality of both ping and traceroute commands in the network setup to acquire relevant dataset.
- Established the need of a four parameters model in comparison to the two parameters model utilizing rule viewer technique and independent T-test method. When the models output QoE values were evaluated using rule viewer technique, it was noted that there was a difference in QoE values obtained for analysis. Basing on the captured data from the designed experiment using linux MTR tool, When delay is 115MS, Jitter is 1MS, packet loss is 0% and throughput is 10 mb/s, the QoE value in the model consisting of four variables tends to produce a

QoE of 2.77, while when the same dataset used for delay of 115MS and throughput of 10 mb/s being used in the model consisting of two variables (delay and throughput) it tend to produce a QoE of 4.59.Likewise, independent T-test method reflected the same effect whereby the p-value based on a confidence interval of 0.95 was 0.017, indicating a mean performance significant difference between the 2 models.

It’s good to note other works like of Farid et al., 2014 utilized throughput, delay, packet loss and jitter however that work concentrated on quantification in wireless and mobile networks while this study concentrated on local area network. Moreover, this study concentrated on integrity of service parameters: Delay, jitter, packet loss and throughput in combination with five input linguistic terms: High, low, very high, very low and medium, five output linguistic terms: Excellent, good, poor, bad, and fair, four variables: Jitter, packet loss, delay and throughput unlike in Farid et al., 2014 work.

5.3 Limitations of the study

- This work utilized fuzzy logic methodology rather than other techniques like support vector machine, neural network, decision tree, naive bayes etc. The limitation was that the model was to be developed with other methods or techniques and the results compared with the developed fuzzy logic model in order to test the effectiveness of other methods/techniques.
- This work selected Mamdani fuzzy inference system (FIS) and not Sugeno FIS. This was a limitation since it is advisable to use both FIS to develop the model in order to have clear comparison of the two FIS results and choose the best for use.
- In this work, accessibility and/or retainability QoE parameters were not handled. The respective underlying QoS-related parameters were to be incorporated into the model to test the effectiveness of the model which was not part of the scope.

5.4 Recommendations/future work

Based on the limitations, it is greatly commended to adopt frameworks having the capabilities to accept vague and subjective values for analysis and decision making based on certain concepts or methodology for instance fuzzy logic as user satisfaction is subjective in nature.

Likewise, it is greatly recommended to develop the model with both fuzzy inference systems (FIS) in order to determine the output values obtained and viability of both Mamdani and Sugeno FIS.

Similarly, as mentioned in the limitation, accessibility and/or retainability QoE parameters were not considered in this work. It's recommended to include the respective underlying QoS-related parameters to test the effectiveness of the model. The respective underlying QoS parameters for accessibility, retainability and integrity of service QoE parameters are denoted in Table 2.1.

Apart from Internet service providers (ISPs); this model can be customized to analyze the assessment of users' experience of web browsing, in qualitative performance measurement of supply chain management, evaluating quality of experience of Haptic-based applications etc.

5.5 Conclusion

In conclusion, this research work refined, tested and evaluated performance of developed model with existing computer network QoE model grounded on fuzzy logic methodology. The model analyzed the QoS provided by the service providers as perceived by the end users. This research work proves the fact that assessment of network QoE is demanding as it attempts to quantify a subjective metric while users' judgement lean on several dynamics which are difficult to be quantified. In this regard, fuzzy logic framework is capable to accommodate a wide range of values for assessing QoE. Moreover, it considers uncertainty in networks by use of linguistic terms for instance high, very low, very high, medium and low thus achieving viable effects for QoE evaluation.

Likewise, there was a vast challenge during extraction of network QoE data used in the analysis. These factors ranged from the type of tool to use, the kind of data to acquire, the method to use for data cleansing to make it relevant for use etc. Inferencing to this work, it was strongly evidenced that linux MTR as one of the best tools for this purpose as it implements the functionality of both ping and traceroute commands in the network setup to acquire relevant dataset.

The main concern in these research activities was to implement fuzzy logic approach for advancement in exploration and assessment of computer networks QoE. Comparison analysis outcome of the developed model with the existing model indicated that there is noteworthy difference in mean performance between the developed four parameters and existing two parameters models since the p value identified in sig (2-tailed) was 0.017. The target population for this model is the ISPs' clients. This will enable ISPs to have the best responsive measures to deal with clients' QoE parameters so as to meet the QoS as per SLAs.

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APPENDICES

Appendix I: Work plan

Project schedule

January 2020- February 2020: Proposal improvement

March 2020-April 2020: Data collection and analysis

May 2020-June 2020: Experiment & progress reports

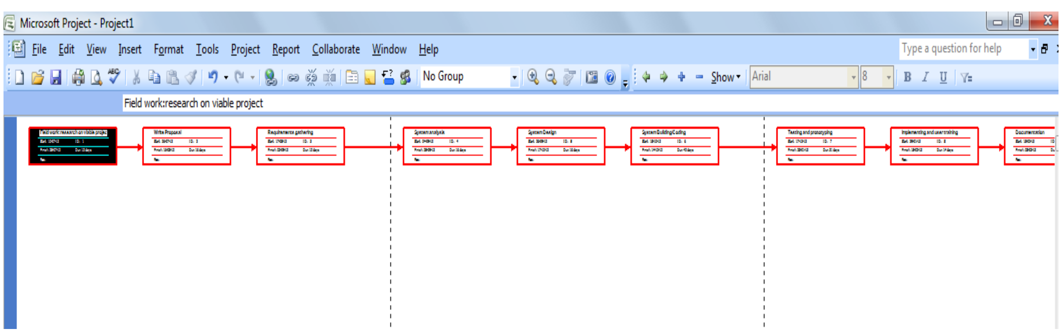
July 2020- August 2020: Discussion and conclusion

September 2020-December 2020: Publications

January2021-March 2021: Exit seminar & submission of work

Appendix II: Work plan table

	Activity	Jan-Feb 2020	March-April 2020	May-June 2020	July-Aug 2020	Sept-Dec 2020	Jan-March 2021
1	Proposal improvement						
2	Data collection and analysis						
3	Experiment & progress reports						
4	Discussion and conclusion						
5	Publications						
6	Exit seminar & submission of work						



Appendix III: Budget table

Project particulars	**Quantity**	**Unit price**	**Total price(KEs)**
MATLAB software	1	12000	12000
Publication charges	5	20,000	100000
Operating system i.e. windows o/s	1 user	12000	12000
MS office 2016	1user	10000	10000
External hard disk	1	7000	7000
Flash disk	2	2000	4000
3G internet modem	1	3000	3000
Total Cost (KES)	**148,000/=**		

Appendix IV: **Publications**

https://dl.acm.org/doi/10.1145/3415088.3415099

https://ijcat.com/archieve/volume8/issue4/ijcatr08041008

http://ijcat.com/archieve/volume8/issue5/ijcatr08051011

https://sites.google.com/site/ijcsis/vol-17-no-4-apr-2019

http://www.theijes.com/Vol8-Issue4.html